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FOCUS

INSIDE THE DINOSAUR'S MIND

HOW BRAINS, NOT BRAWN, HELPED THE TYRANNOSAUR BECOME KING

PLUS
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What we've
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The answer is
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ALIENS AND THE MULTIVERSE

Our Universe might not be one of a kind

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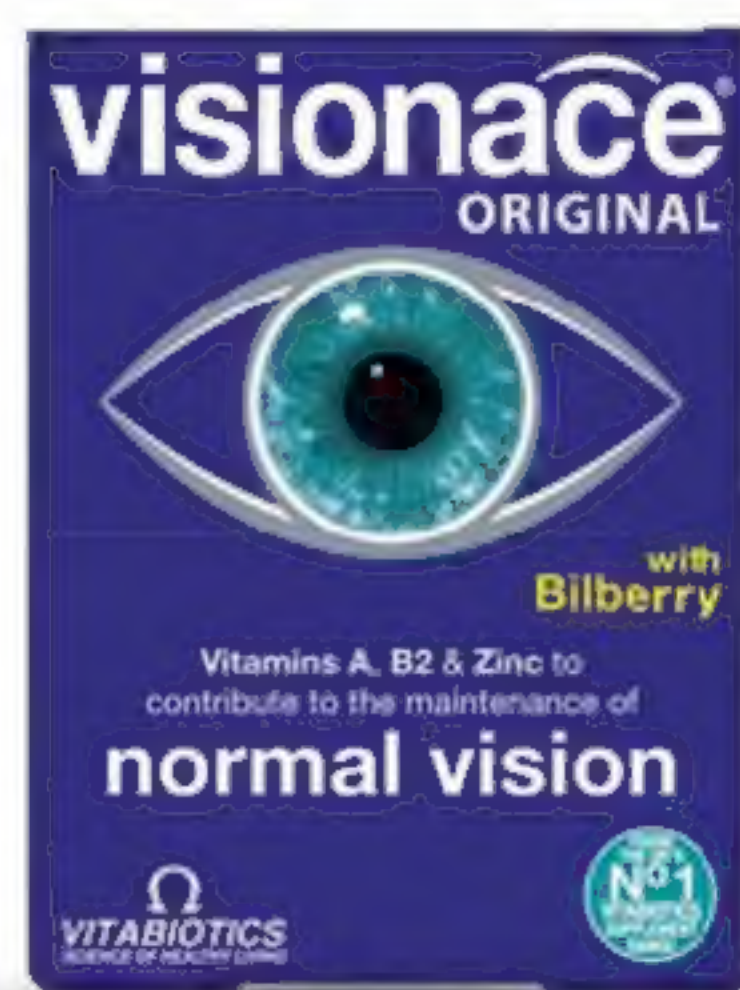


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Elephants can talk to each other from **6km away** → p20

WHAT WE'VE FOUND OUT THIS MONTH

A Chinese school is using AI cameras to **spy on its students** → p30



Fish can cheat, and apologise afterwards → p56



Ocean tides create **magnetic fields** → p88



Daisy petals close up when **rain is on the way** → p94



WELCOME



Bigger than a bus, daft as a brush: that's the *T. rex* I remember. A monstrous predator made friendly by a pair of drumsticks for arms and a walnut for a brain. Of course, in its element, *T. rex* would have been terrifying, with its monstrous maw and blood-curdling roar. But if cinema's taught me anything it's that if I'm unlucky enough to stumble across one, then I can easily outwit it by standing still.

It turns out, the films were wrong (thanks, Spielberg!). As with most apex predators, the *T. rex* didn't just muscle its way to the top of the food chain, it used cunning to get there. And this story, of how a tyrannosaur became king, is one that scientists are beginning to piece together. Turn to p38 where we pick up the thread with a pair of dinosaur hunters who meet in Berlin to exchange a package concealed in a Soviet box.

Clearly, it would be a lot easier to understand Earth's previous tenants if we could look back in time. It turns out that some physicists think this might not be such a crazy idea. Astrophysicist and author Marcus Chown takes a look at the many ways scientists have been trying to wrap their head around the possibilities of time travel on p50.

And now, it's over to you. We'd love to find out what you think of *BBC Focus*, to help us shape the direction of the magazine. Turn to our reader survey on p71, or complete it online at sciencefocus.com/readersurvey. All completed entries will be submitted into a prize draw for a chance to win one of four £100 Amazon vouchers. Enjoy the issue!

Daniel Bennett

Daniel Bennett, Editor

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STEPHEN BRUSATTE

We've got a lot wrong about dinosaurs over the years, especially when it comes to their intelligence. Palaeontologist Stephen sets us straight. → p38



ALICE GREGORY

The latest research says that getting enough sleep is about more than simply recharging your batteries. Sleep expert Alice investigates. → p65



HELEN SCALES

Fish have a reputation for having short memories and little brainpower. This couldn't be further from the truth. Marine biologist Helen plunges in. → p56

CONTACT US

➔ Advertising

neil.loyd@immediate.co.uk
0117 300 8276

➔ Letters for publication

reply@sciencefocus.com

➔ Editorial enquiries

editorialenquiries@sciencefocus.com
0117 314 7388

➔ Subscriptions

bbcfocus@buysubscriptions.com
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WANT MORE?

Don't forget that *BBC Focus* is also available on all major digital platforms. We have versions for Android, Kindle Fire and Kindle e-reader, as well as an iOS app for the iPad and iPhone.



Can't wait until next month to get your fix of science and tech? The Science Focus website is packed with news, articles and Q&As to keep your brain satisfied. sciencefocus.com



SPECIAL ISSUE



MIND-BENDING SCIENCE SIMPLY EXPLAINED

In this special edition from *BBC Focus*, we investigate some weird science, such as wormholes, quantum physics, space-time and gravitational waves. buysubscriptions.com/focuscollection

EYE OPENER

Caves of wonder

LECHUGUILLA CAVE,
NEW MEXICO

This is Lake Castrovalva, located inside the Lechuguilla Cave in New Mexico. When Lechuguilla was fully opened up for exploration in 1986, a rare variety of speleothems – mineral formations – was discovered, including the rimstone dams pictured. “They are formed at the air/water interface,” says microbiologist Dr Hazel Barton, who studied these caves. “When water splashes over the edge, it changes the partial pressure of the dissolved CO₂ in the water, causing it to off-gas. This causes the pH to change, which makes the calcium carbonate precipitate out so it adds itself to the edges. Based on where they are and how thick they are, I expect they took at least 500,000 years to form. Lake Castrovalva is a pretty special place. I’ve maybe only seen one or two other places where they form to this extent.”

The caves are home to several species of previously unknown microorganism, including some that may have medicinal properties – and one that, despite being four million years old, is resistant to modern antibiotics.

PHOTO: ROBBIE SHONE/NATIONAL GEOGRAPHIC IMAGES









EYE OPENER

Going batty

**GORONGOSA
NATIONAL PARK,
MOZAMBIQUE**

Arachnophobes, relax. That's not a spider but a bat fly – a type of parasite that's co-evolved with bats over millions of years. During evolution, the bat fly lost its wings and developed a flat, tough body just a few millimetres long. It can tuck its head into a protective groove in its back when it's resting, making it almost impossible to squash.

Bat flies rarely leave their hosts and reproduce in an interesting way. "They give birth to live young," says Dr Erica McAlister, curator of Life Sciences at the Natural History Museum. "Bat flies only have one larva at a time and they put a huge amount of their resources into it.

They produce an egg internally and the mother has an internal lactating gland to provide milk."

One of these bats can play host to up to six or seven blood-feeding bat flies, which hold on to the bat's fur with claws on their legs. No wonder the bat doesn't look happy about it.

REPLY

Your opinions on science, technology and *BBC Focus*

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BBC Focus, Tower House,
Fairfax Street, Bristol, BS13BN

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MESSAGE OF THE MONTH

Help dogs breathe easily

In the otherwise fabulous Q&A section in the May issue, you use a photo of two British bulldogs to illustrate the question 'Do dogs recognise their own breeds?' (p82). I'm not sure if you're aware, but the British Veterinary Association (BVA) is keen to discourage the media from using extreme conformation breeds – those bred for particularly acute physical characteristics – in their publications, especially in adverts. The British bulldog is classed as an extreme conformation breed. Their identifying traits – the flattened noses, narrowed nostrils, severely reduced nasal chambers and excessively saggy flesh in the pharynx – all contribute to brachycephalic obstructive airway syndrome (BOAS), which is the huffing and puffing that people expect from bulldogs and pugs. And don't get me started on the skin, eye and thermoregulatory problems!

I was wondering if you'd consider avoiding using images of the extreme conformation breeds, such as bulldogs and pugs, in future? Perhaps you could even write an article on what we're doing to these breeds? It's a tragedy and the general public needs to know about it. Please have a look at the BVA website for more info (bit.ly/BVA_dog). As a vet, I see too many of these animals living half-lives of pain, suffering and partial suffocation, which their owners think is normal. I try to explain and educate, but often my advice falls on deaf ears, either because owners don't see the issue or don't want to accept that their beloved pet, which may have cost them over £4,000 to acquire, is so biologically flawed.

Paige Hunter BVSc MRCVS, via email

➔ Good point, well made. We'll keep an eye on it in the future.
– Daniel Bennett, editor

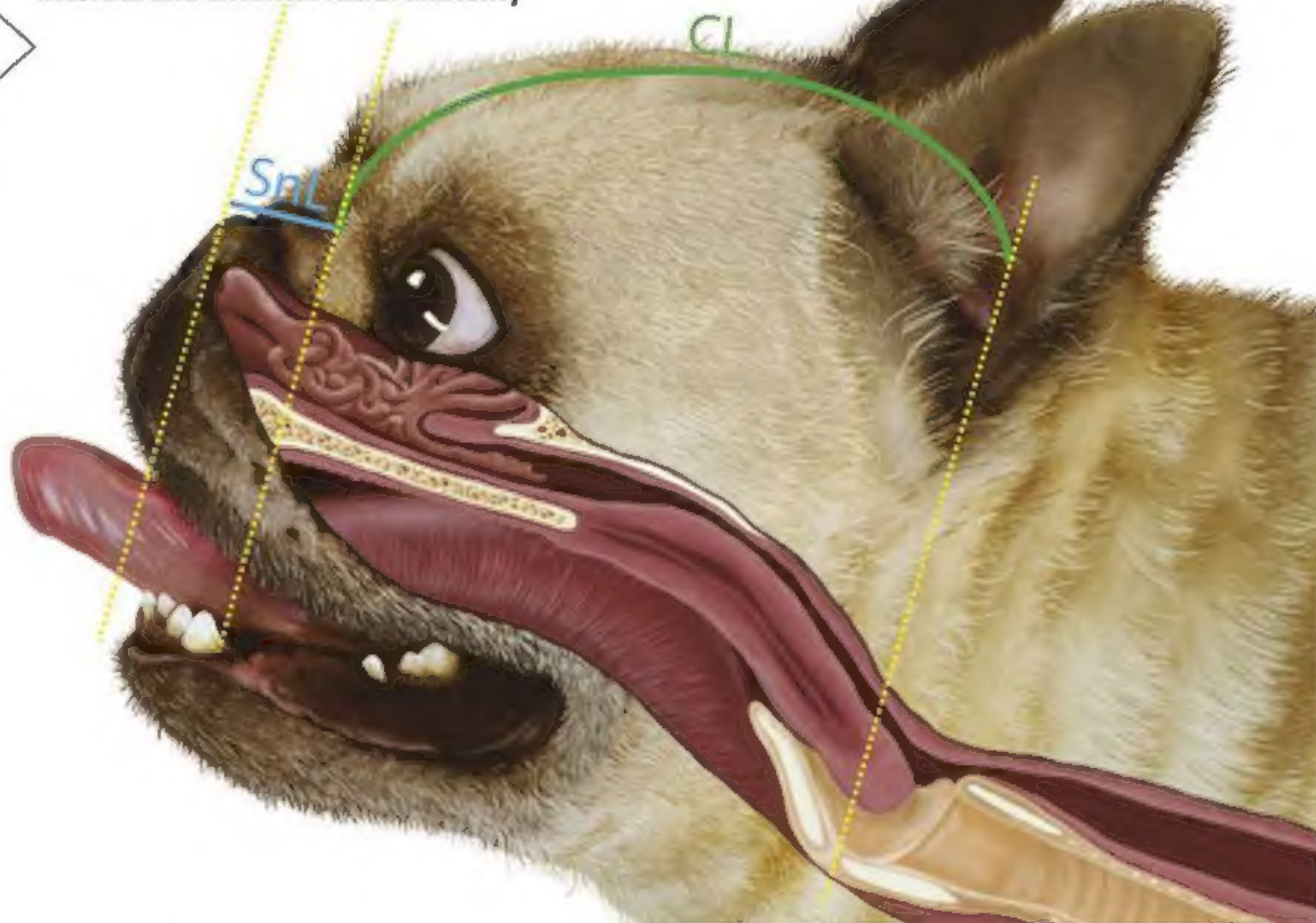
WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* will win a **Perfection Pillow** from sleep-tech company Reflex. It's designed to eliminate the causes of sleep deprivation, including neck and back pain, teeth grinding, snoring and sleep apnoea. reflexpillow.com



WORTH
£57

Squashy-faced dogs suffer from restricted breathing. Taking measurements like the cranium length (CL) and snout length (SnL) helps illustrate the relationship between the dogs' internal and external facial anatomy



Back in black

In Helen Czerski's feature (March, p70) she explains how black clothes worn in hot weather absorb more heat than white clothes. But also that since black clothing also radiates more heat than white, black is okay to wear in the heat.

Helen's right, black does radiate as much heat as it absorbs – but it does so at a higher temperature. A beekeeper in Britain demonstrated this by painting some panels various colours, leaving them out under the Sun and then taking their temperatures. He decided his beehives should be painted white because the other coloured panels were all hotter and the black panel was 10°C

hotter than the one painted white. (Although, interestingly, the beekeeper reported that a dark red panel ended up being hotter than the black one.)

Similarly, a black car that's parked in the hot sunshine will radiate as much heat as it absorbs at a temperature of 30°C, for example, but a white car will be radiating the heat it absorbs at 20°C – quite a difference.

Also, on p96 of the March issue you answer the question 'Why do astronauts always wear white suits?' And the reason is to counter the extremes of heat and cold in space – white best reflects heat from the Sun and radiates the least heat from the astronaut.

Donovan Gericke, Stilfontein, South Africa



This far but no further

Is it possible that there's a natural plateau with regard to computer technology that coincides with our ability to live with it? In the May issue (p72), you point out that microchip manufacturers are unable to keep pace with the continual increases in processing power predicted by Moore's Law. But it seems strange that we appear to be reaching this point just as more and more people are choosing to reject, avoid or at least limit their exposure to things like social media and smartphones. Could the two be related?

Tom Hatch, London

Wormhole let down

I enjoyed Robert Matthews's feature in the June issue (p38). Through popular sci-fi films and shows such as *Stargate*, *Farscape* and *2001: A Space Odyssey*, wormholes gave someone like me hope that we could spread out across the Galaxy, and perhaps the Universe, through these rips in space-time. So you can imagine my disappointment when I discovered, towards the end of the article, that even if we were able to find a stable wormhole, it'd take us

Wormholes = big tunnels of disappointment

longer to travel through it than if we'd just travelled to where it would spit us out by conventional means! Talk about an anticlimax.

Frank Wilson, Dulwich

Meanwhile over on Twitter...

Helen Czerski bid *BBC Focus* readers farewell ahead of her final column in the next issue.

@helenczerski All good things come to an end, & after 78 (I think) columns for @sciencefocus over the last 6.5 years, I've just filed my last one. Huge thanks to them for letting me write about all sorts of bonkers things, and to @GrahamSouthorn for inviting me to do it in the first place.

@GrahamSouthorn Ah, thanks Helen – it's nice to be remembered! Always enjoyed reading your column – I learned something new every month. Best of luck with your books and TV presenting – I look forward to future programmes.

@cthuui But that's the best bit!

@Tara_McElwain Really loved to read your columns every month. They will be missed.

BBC FOCUS

EDITORIAL

Editor Daniel Bennett
Production editor Alice L. pscombe-Southwell
Commissioning editor Jason Goodyer
Online editor Alexander McNamara
Staff writer James Lloyd
Editorial assistant Helen Clenny
Science consultant Robert Matthews

ART

Art editor Joe Eden
Deputy art editor Steve Boswell
Picture editor James Cutmore

CONTRIBUTORS

Hani Abusamra, Philip Ball, Rob Banino, Peter Bentley, Stephen Brusatte, Jy Chamary, Marcus Chown, Charlotte Corney, James Croft, Helen Czerski, Emma Davies, Russell Deeks, Rebekka Dunlap, Alexandra Frank, In-Cheung, Alice Gregory, Alistair Gunn, Clive Hamilton, Merijn Hos, Christian Jarrett, Raia Lockett, Magic Torch, Mark Lorch, Michael Mosley, James O'Steen, Helen Picher, Dean Purnell, Kouzou Saka, Helen Scales, Seth Singh, Luis V. Iazon, Joe Vva-dron

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Group advertising manager Tom Drew
Advertising manager Neil Lloyd
Senior brand sales executive Jonathan Horwood
Brand sales executive Beth Gregory
Senior classified executive Jenna-Vie Harvey
Newstrade manager Rob Brock
Subscriptions director Jacky Perales-Morris
Direct marketing manager Kele Lane

MARKETING

Head of apps and digital edition marketing Mark Summerton

ISLETS

Laurence Robertson 00353 876 902208

LICENSING & SYNDICATION

Director of licensing and syndication Tim Hudson
International partners manager Anna Brown

PRODUCTION

Production director Sarah Powe
Senior production coordinator Derrick Andrews
Ad services manager Paul Thornton
Ad coordinator Jade O'Halloran
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Content director Dave Musgrove
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CEO Tom Bureau

BBC STUDIOS, UK PUBLISHING

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Director of consumer products and publishing Andrew Moultrie

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Publisher Mandy Thwaites

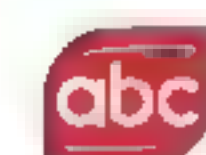
Publishing coordinator Eva Abramik
Contact UK Publishing@bbc.com
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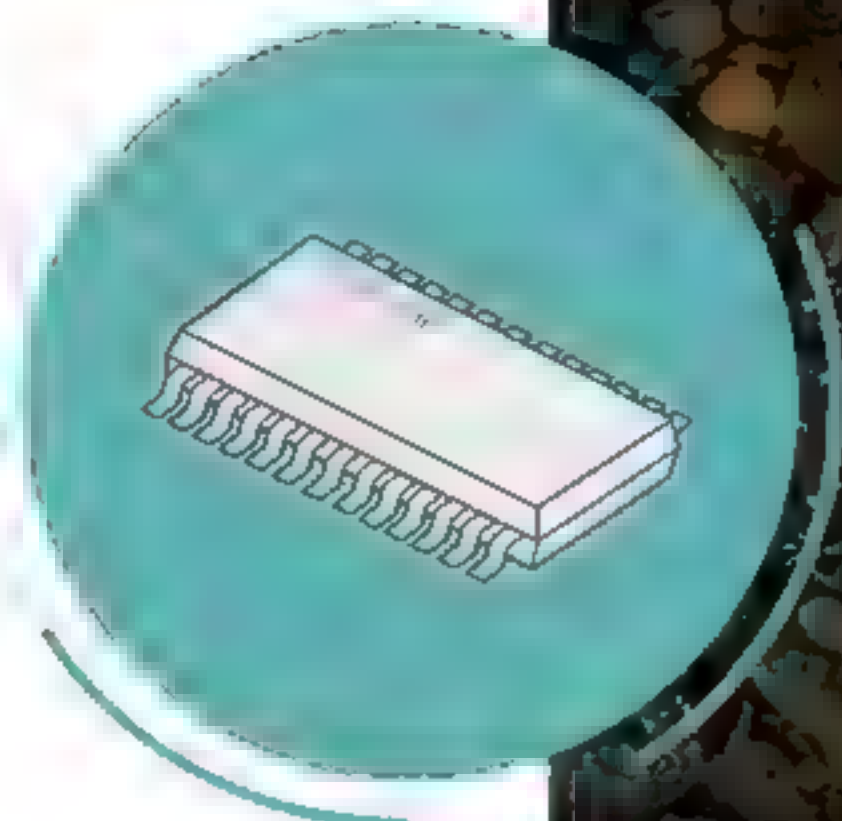
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ADVERTISEMENT FEATURE



DACS ENTERTAINMENT

NEXT-GENERATION SOUND QUALITY GETS PC-LIKE POWER

Today's music-lover has never had it so good: the vinyl revival, internet radio, plus the growing popularity of music streaming, like Spotify, Amazon Music and Google Play Music services. We're even able to enjoy recording studio sound quality (better than CD) with the right equipment.

Most of today's music is digital and there's one crucial piece of electronics that determines how good that music can ultimately sound: a DAC (digital to analogue convertor). The chances are, you've already used a DAC in the past 24 hours: that smartphone call, TV news catch-up or internet surf; DACs are essential circuit board devices embedded into everyday gadgets converting digital signals into analogue ones, so you can hear them.

Most are tiny chips, costing no more than a few pounds, machine-soldered into circuit boards, like the one in your phone. At the opposite end of the scale, however, are external, matchbox-sized DACs that plug in to smartphones, tablets, laptops, computers, TVs, hi-fis and more, to upgrade (and transform) sound quality. The difference can be likened to HD video: suddenly music has more clarity, more resolution and is more "real".

The world leader in DAC technology is British. Kent-based Chord Electronics has been making award-winning DACs using proprietary technology since 1996. Having discovered basic chip-DACs sounded awful, it applied computer-like levels of processing power to the task, employing highly advanced programmable devices (FPGAs), custom-coded by its expert audio designers.

Chord Electronics' DACs, from the smartphone-enabling rechargeable Mojo to the Hugo 2 (pictured) are hand-made in the UK with British design, expertise and software. The company has the most advanced digital technology the world has to offer and has accumulated more major awards than anyone else. To experience your favourite music in HD, search 'Chord Electronics Mojo' to begin your journey of discovery.



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DISCOVERIES

DISPATCHES FROM THE CUTTING EDGE

JULY 2018

EDITED BY JASON GOODYER

PHYSICS

LIFE IN THE MULTIVERSE

Computer simulations involving dark energy suggest our Universe may not be as unique as we once thought...



If our Universe is one of many making up a much larger multiverse, life could be common in countless other parallel universes, according to researchers from the University of Sydney, the University of Western Sydney, the University of Western Australia, and Durham University.

According to the multiverse theory, life arose in our Universe thanks to the amount of dark energy being just right. The theory states that if the amount of dark energy in a universe is too large, it causes such a rapid expansion that it prevents any stars, planets or life from forming. If it is too small, then the universe collapses again before anything interesting forms. Dark energy is the mysterious force that is accelerating the expansion of the Universe that started with the Big Bang.

Yet when the team ran simulations using the EAGLE project (Evolution and Assembly of GaLaxies and their Environments) – one of the most realistic computer simulations of the Universe ever created – they found that adding dark energy up to a few hundred times the amount observed in our Universe actually had a modest impact upon star and planet formation.

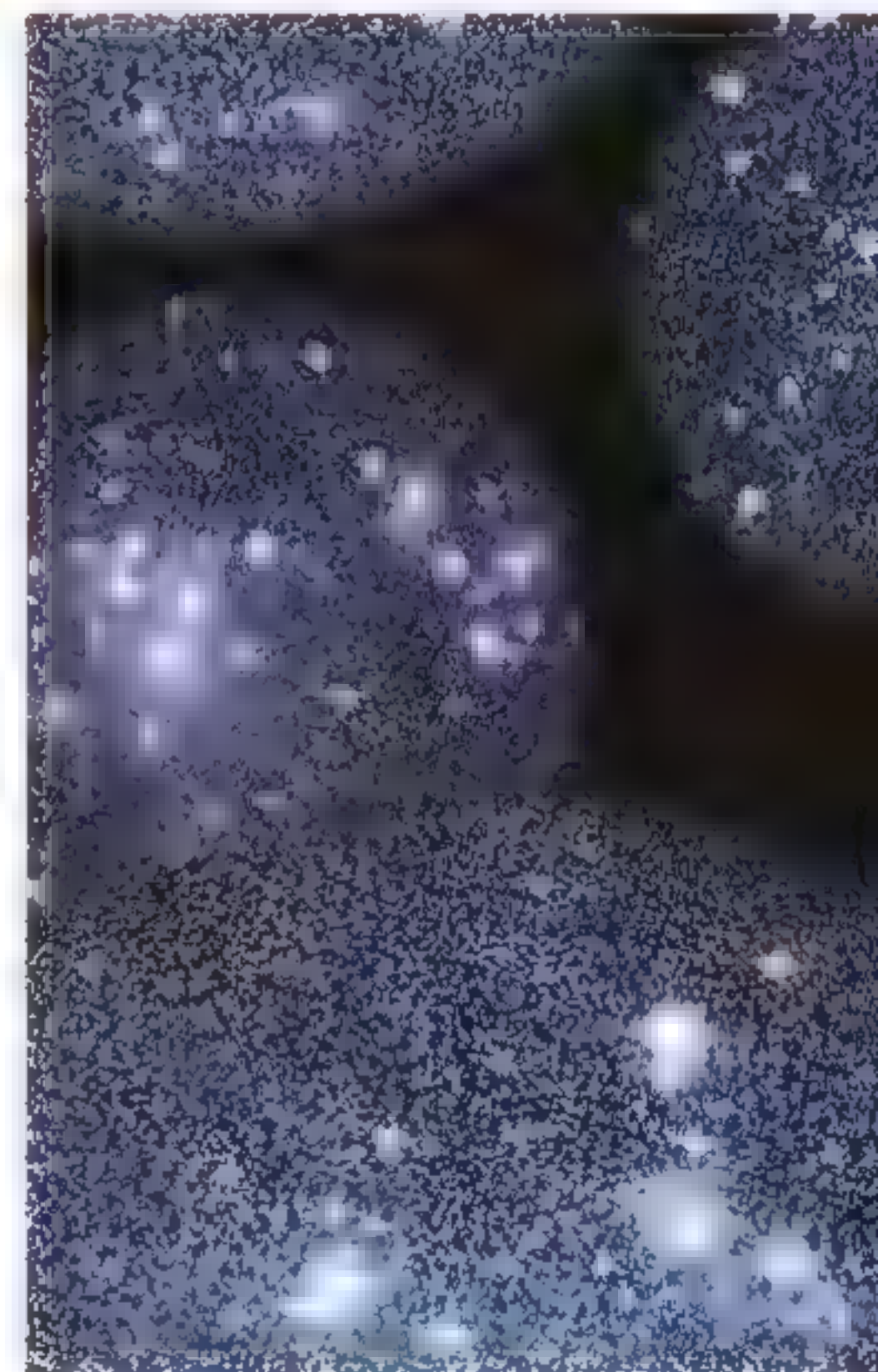
“For many physicists, the unexplained but seemingly special amount of dark energy in our Universe is a frustrating puzzle,” said Jaime

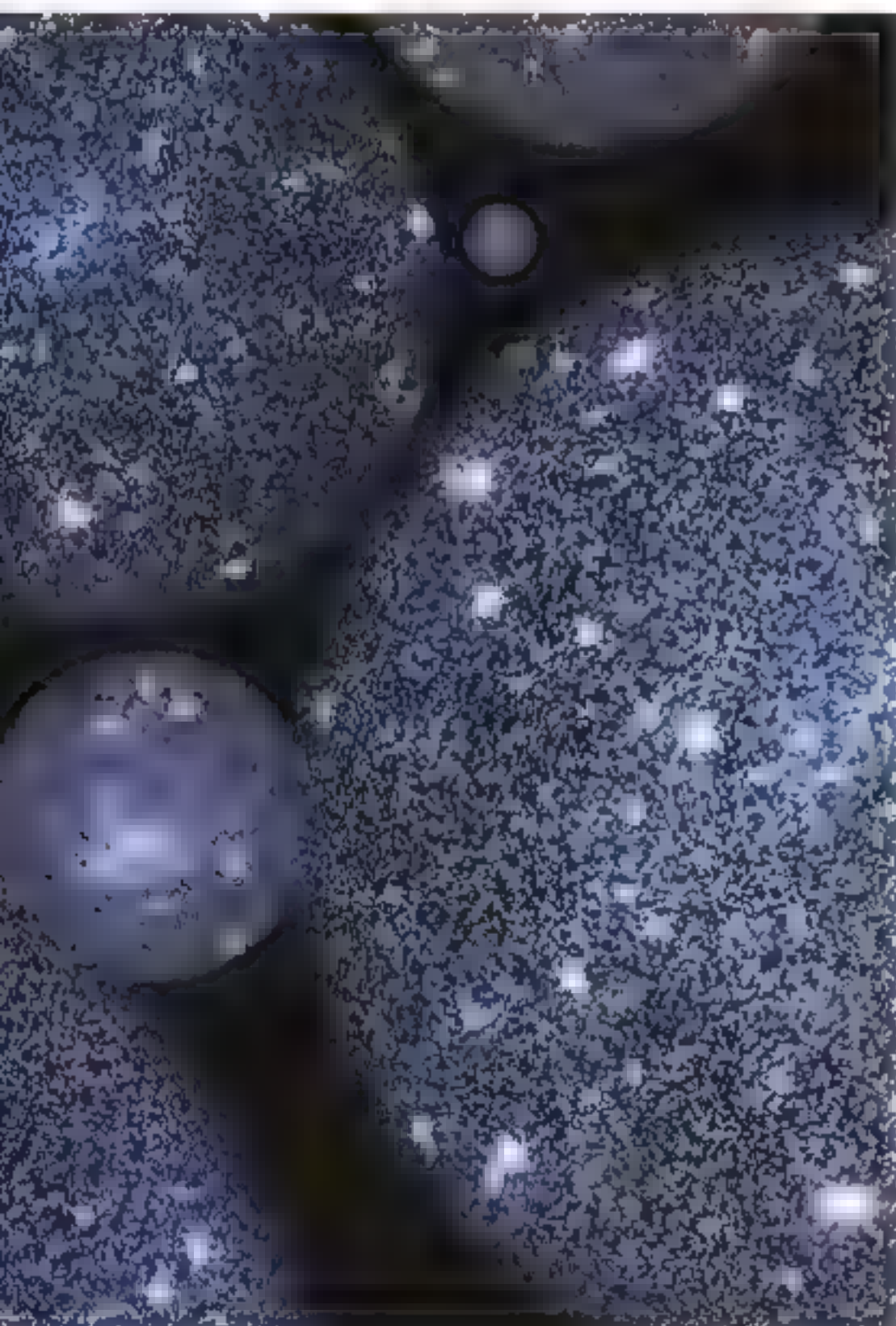
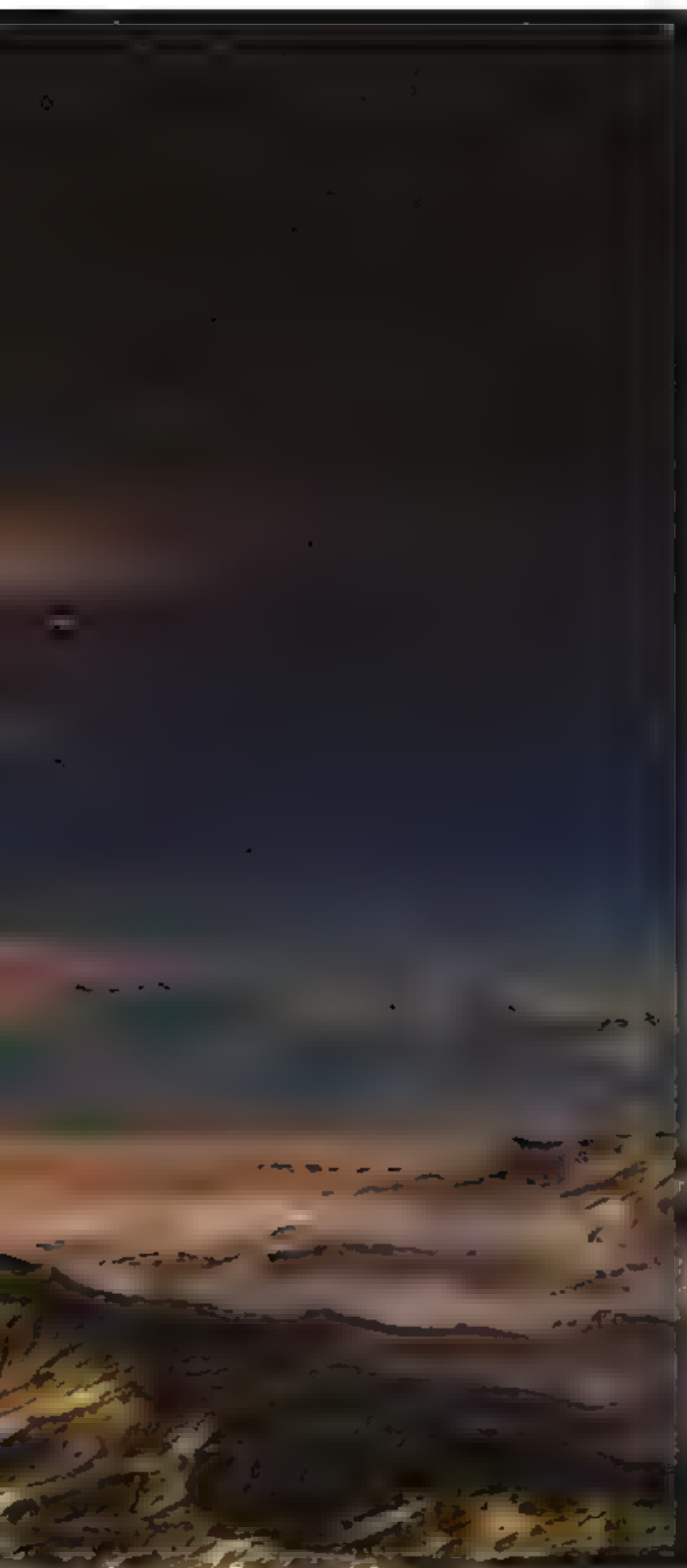
“FOR MANY
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Salcido, a researcher at Durham University who took part in the research. “Our simulations show that even if there was much more dark energy or even very little in the Universe then it would only have a minimal effect on star and planet formation, raising the prospect that life could exist throughout the multiverse.”

However, there is one rather large hitch. The researchers also found that if we do live in a multiverse, we’d expect to observe much more dark energy than we do – perhaps 50 times more.

“The formation of stars in a universe is a battle between the attraction of gravity, and the repulsion of dark energy,” said Durham University’s Prof Richard Bower, who also took part in the research. “We have found in our simulations that universes with much more dark energy than ours can happily form stars. So why such a paltry amount of dark energy in our Universe?”





TOP: Even universes with much more dark energy than ours could still form stars and planets, like this alien world

ABOVE: The multiverse is a version of the cosmos in which there are multiple universes

HEALTH

Nanoparticles extracted from tea offer hope of new lung cancer treatment



dots extracted from tea leaves can kill cancer cells – sadly you don't get these benefits just from drinking the stuff

Somebody put the kettle on: nanoparticles extracted from tea leaves can inhibit the growth of lung cancer cells, killing up to 80 per cent of them, researchers at Swansea University have found. The team made the discovery by accident when testing out a new method of creating quantum dots – tiny semi-conducting particles measuring less than 10 nanometres in size that display a wide range of unique properties.

Quantum dots have shown promise in several different applications, including computers, solar cells, healthcare and tumour imaging. However, they are complicated and expensive to manufacture and create toxic by-products.

After attempting to create a method of producing non-toxic nanoparticles using

extracts from tea leaves for use in the imaging of tumours, the team noticed something astounding: the quantum dots they had created were penetrating into the pores of the cancer cells and killing them from the inside out.

“Building on this exciting discovery, the next step is to scale up our operation, hopefully with the help of other collaborators,” said Dr Sudhagar Pitchaimuthu, who was a lead researcher on the project. “We want to investigate the role of tea leaf extract in cancer cell imaging, and the interface between quantum dots and the cancer cell. We would like to set up a ‘quantum dot factory’ which will allow us to explore more fully the ways in which they can be used.”

NEUROSCIENCE

MEMORIES 'TRANSPLANTED' FROM ONE CREATURE TO ANOTHER

In a world first, researchers at UCLA claim to have successfully transferred a memory from one sea slug to another using RNA. RNA is a molecule involved in the carrying of genetic instruction and the building of proteins.

The researchers periodically gave mild electric shocks to the tails of a species called *Aplysia californica*, or the California sea hare, over 24 hours in order to provoke their defensive withdrawal reflex. When subsequently tapped, the animals displayed a defensive contraction that lasted for 50 seconds. By contrast, sea slugs that had not been given the shocks contracted for about one second.

They then extracted RNA from the nervous systems of sea hares that received the tail shocks, and injected it into seven animals that had not received any shocks. They found that these ones then displayed a

defensive contraction that lasted an average of about 40 seconds when tapped.

"It's as though we transferred the memory," said UCLA's Brain Research Institute's Prof David Glanzman. "I think in the not-too-distant future, we could potentially use RNA to ameliorate the effects of Alzheimer's disease or post-traumatic stress disorder."

The finding questions the current theory that memories are stored in synapses. Synapses are junctions between two nerve cells, consisting of a minute gap across which chemical signals are carried by messenger chemicals called neurotransmitters. Glanzman, however, proposes a new theory in which memories are stored in the nucleus of neurons.

"If memories were stored at synapses, there is no way our experiment would have worked," said Glanzman.

FACT BOX

The cellular and molecular processes seem to be very similar between marine slugs and humans, even though the slug has about 20,000 neurons in its central nervous system and humans are thought to have about 100 billion.

Sea hares are named for the bunny-ear-like sensory structures called 'rhinophores' that emerge from their heads. Sea hares can also release 'ink' when disturbed, as seen here.

IN NUMBERS

8

The age, in weeks, that puppies reach peak cuteness, as estimated by a team at Arizona State University. This is the age at which they are weaned by their mothers.

120

The age, in years, of a sourdough starter (a yeast culture used to make bread) owned by 84-year-old Lone Christensen who lives in the Yukon, Canada.

73

The speed, in kilometres per second, of the new figure for the Hubble constant – the speed at galaxies are moving away from the Earth. This was calculated by researchers at the Space Telescope Science Institute in Baltimore, Maryland.

ASTRONOMY

NEW IMAGES FROM HUBBLE RELEASED

Meet your cosmic neighbours: images assembled by an international team of researchers using data from NASA's Hubble Space Telescope show the closest galaxies to Earth in unprecedented detail.

Dubbed the Legacy ExtraGalactic UV Survey (LEGUS), the project combined data from observations in visible and UV light of 50 star-forming spiral and dwarf galaxies in the local Universe, ranging from 11 to 58 million light-years away. The resulting catalogue will provide researchers with a large and extensive resource for understanding the complexities of star formation and galaxy evolution, the team said.

"Much of the light we get from the Universe comes from stars, and yet we still don't understand many aspects of how stars form," said team member

Elena Sabbi of the Space Telescope Science Institute in Baltimore, Maryland. "This is even key to our existence – we know life wouldn't be here if we didn't have a star around."

The team members chose the galaxies based on their mass, star-formation rate, and abundance of elements that are heavier than hydrogen and helium. The resulting catalogue contains around 8,000 star clusters ranging from 1 to 500 million years old, and around 39 million stars ranging from 1 million to

several billion years old.

"By seeing galaxies in very fine detail – the star clusters – while also showing the connection to the larger structures, we are trying to identify the physical parameters underlying this ordering of stellar populations within galaxies," said survey leader Daniela Calzetti of the University of Massachusetts, Amherst. "Getting the final link between gas and star formation is key for understanding galaxy evolution." See the images at legus.stsci.edu

These new images of our closest galaxies could help explain how stars form

MARS

HELICOPTER JOINING MARS 2020 MISSION

NASA has built a helicopter that's light and powerful enough to fly in Mars's thin atmosphere, and it'll travel to the Red Planet as part of the Mars 2020 Rover mission.

The helicopter weighs just under two kilograms and has two rotors stacked on top of each other that spin in opposite directions at almost 3,000rpm – 10 times the rate of a helicopter on Earth – to keep it in the air in the thin Martian atmosphere. It is clad with solar cells to charge its lithium-ion batteries and is fitted with a heating mechanism to prevent it from freezing over during the chilly Martian nights.

"The altitude record for a helicopter flying here on Earth is about 40,000 feet [12,192m]. The atmosphere of Mars is only 1 per cent that of Earth, so when our helicopter is on the Martian surface, it's already at the Earth equivalent of 100,000 feet [30,480m] up," said Mimi Aung, the project manager of Mars Helicopter at NASA's Jet Propulsion Laboratory. "To

make it fly at that low atmospheric density, we had to scrutinise everything, make it as light as possible while being as strong and as powerful as it can possibly be."

The helicopter will travel to the Red Planet with the Mars rover as part of its 2020 mission. The rover will deliver the helicopter to a suitable launch site, where it'll embark on its first flight: a short vertical climb three metres off the ground, followed by a 30-second hover. Over the next 30 days of testing, it'll gradually build up to flights of a few hundred metres. Since Earth is a several light-minutes away, there's no way for humans to control the flights in real-time. Instead, the helicopter will pilot itself, with the ability to receive and interpret commands.

If successful, the project will prove that helicopters can be used as low-flying scouts on Mars, and pave the way for other, more ambitious, projects.

If the Mars helicopter is a success, then low-flying scouts could be used to offer a bird's-eye view of the Red Planet



LIGHT MINUTES?

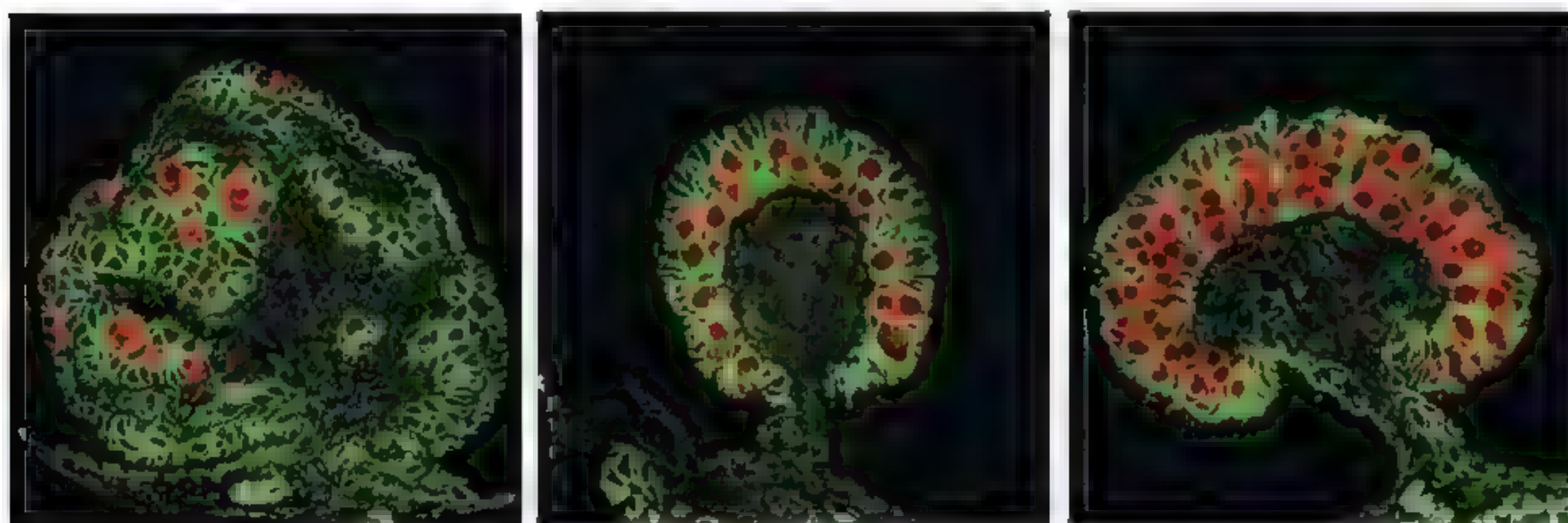
The number of minutes it takes light to travel a given distance. Radio waves travel at the speed of light, so light-minutes are useful for describing lags in communication.

ZOOLOGY

COLDER INCUBATION MAKES BABY TURTLES MALE, AND NOW WE KNOW HOW



Red-eared sliders are referred to as turtles in the US, but in the UK we call them terrapins. They are native to the US, but have been introduced to many other countries due to their popularity as pets



The centre image is a developing turtle gonad that was incubated at a temperature that should have turned it into a testis (left). But when the researchers knocked down its *Kdm6b* gene, it started turning into an ovary (right) instead

While a genetic coin-flip determines the sex of a human baby, turtles have a more interesting method. A turtle egg hatches male or female depending on the temperature of its nest, and scientists from Duke University in the US and Zhejiang Wanli University in China have found out how that mechanism works.

For a common species called the red-eared slider, eggs incubated at 32°C produce female hatchlings, while those at 26°C hatch as males. This study showed that cooler temperatures turn on a gene called *Kdm6b* which in turn flicks a biological switch called *Dmrt1* triggering the development of testes and resulting in the birth of a male turtle. If that gene is not turned on, testes don't develop and the turtle hatches as a female.

Kdm6b activates the *Dmrt1* switch by modifying histones; proteins that

wrap themselves around DNA inside the cell nucleus and stop the genes from working.

"It's like taking the brakes off the male pathway," said study co-author Ceri-Weber, PhD candidate.

While it isn't known exactly why turtles and other reptiles have developed this method of sexual differentiation, it can leave them vulnerable to climate change. Dr Blanche Capel, lead author of the study, said that some nests are already producing very few male hatchlings.

"The males who are born at a higher temperatures likely have a genetic make-up that makes them resistant to switching at high temperatures," she said. "And since they're the only game in town, they're going to be producing the next generation. So we can hope that at a population level, nature has a way of sorting this out."

THEY DID WHAT?!

CROCODILES LISTENED TO BACH IN A SCANNER

What did they do?

A team of researchers from Ruhr University Bochum in Germany put year-old Nile crocodiles into an MRI scanner and played them Bach's *Brandenburg Concerto No. 4*.


Why did they do that?

Crocodiles originated over 200 million years ago, and their brains have barely changed since, making them a good modern-day representative of ancient brains. Scientists study crocodiles to understand at which point certain brain structures and behaviours first emerged. The point of the study was to examine how the crocodile brains respond to complex sounds, and see how those compared to the patterns seen in more recently evolved mammals and birds.

What did they find?

Different areas of the crocodilian brain were activated by complex music, such as Bach, compared to those activated by basic notes. The patterns are similar to those seen in mammals and birds exposed to music, suggesting that the ability to process complex sounds was preserved and passed down, and evolved earlier than previously thought.



A photograph of a herd of elephants in a savanna landscape. The elephants are of various ages, with some showing large tusks. They are standing in a line, facing towards the left. The background shows a clear blue sky and some distant trees.

NATURE

"Elephants actually have a whole range of different vocalisations"

Making noises through their trunks isn't the only way elephants communicate. Dr Beth Mortimer of Oxford University reveals their secret language

ABOVE: This herd may not be in visual or aural range of other elephants, yet they may be able to communicate with them by using rumbles

What noises does an elephant make?

In terms of purposeful signals, those are made by vocalisations – using their vocal cords the same way that we do when we're talking. People have heard of 'trumpets', but elephants have a whole range of vocalisations. The ones that go through the ground are known as 'rumbles' because they're infrasonic vibrations – ultrasound is super-high frequency; infrasound is super-low frequency, under 20 Hertz. We can't hear this type of vocalisation but, if you're close enough to an elephant, you can feel it. It's like a super-loud bass. We don't know for sure how the elephants detect ground vibrations, but it's either through sensors *under* their feet – similar to those we have in our skin – or *through* the feet, so the vibration travels up the leg bones to the middle ear, known as a bone-conduction method.

What do the rumbles mean?

There are alarm rumbles, greeting rumbles, 'let's go' rumbles... There's different information content depending on the social situation. The interesting thing about rumbles is that part of the vibration goes through the air, but it goes through the ground as well and not much is known about

what role the physical environment plays on that.

How did you detect rumbles?

For the elephant project, we went into the field in Kenya and used geophones, which are basically microphones for the ground – the same equipment used to monitor earthquakes and processes through the Earth. So we were taking well-established techniques and approaches used in seismology, but applying them to elephant behaviour and conservation monitoring. We were recording vibrations to make computer models and were interested in what effect the different types of soils and landscapes would have.

How far do the signals travel?

There isn't much experimental data, but based on our models, in favourable conditions – low background [noise] and on a sandy terrain – we think it's six kilometres. Certainly over the kilometre range. So when they can't see other elephants or use other signals to detect them, they might be able to use vibrations. They've got the potential for long-distance communication. You play the recordings back to elephants, we



BELOW: The rumbles are picked up either by sensors in the elephants' feet or bone conduction

call this seismic playback, and they only respond to calls from elephants they know. They can even discriminate the identity of the sender.

Why are vibrations useful to study?

If you put ground-based recorders in remote locations, then you can monitor the movements and identity of different types of wildlife in that habitat. Because elephants only really run if they're in distress, we might be able to pick up this 'panic running', which would be useful information of whether there's a poaching threat, for example. Our next plans are to look at how sensitive the elephants are to these vibrations.



DIGESTED READ

Studying ground rumbles, elephants' non-audible method of communication, may provide us with clues to their behaviour and social organisation, but could also contribute to conservation efforts



CHESS PLAYERS

Chess grandmasters live longer than the general population, researchers at the University of Queensland have found. It's not yet clear why, but it's likely to be due to social and economic factors and a reduced risk of developing dementia, they say.

MUSICIANS

Learning an instrument can make your brain more efficient, so it's able to perform a certain task with less effort than the brain of a non-musician, researchers at the Baycrest Centre for Geriatric Care, Canada, have found.

GOOD MONTH

BAD MONTH

MANUAL WORKERS

Men working in physically demanding jobs, such as builders, are at greater risk of an early death despite getting a significant amount of exercise, Dutch researchers have found. The effect, which is thought to be down to the intense demands put on their cardiovascular systems, was not seen in women.

CLASS CLOWNS

This is no joke. Getting up to hijinks in the classroom can make young kids more popular with their classmates. Yet by the time they reach eight years old, classroom jokers are viewed as disruptive annoyances and are less desirable as playmates, a study at the University of Illinois has found.





Splendid fairy wren
males shimmer with
bright blue feathers

ZOOLOGY

BIRDS MAKE FRIENDS WITH OTHER SPECIES BY SINGING SONGS

Songbirds can recognise familiar members of their own species by each individual's unique song. Indeed, studies have also shown that different species of birds recognise and cooperate with each other. But a study recently carried out in Australia suggests that these links may be between specific birds rather than the species in general.

A team from the University of Chicago and the University of Nebraska investigated two species of fairy wrens, variegated and splendid, and found that the birds can recognise particular individuals of the other species. Both species of wren are small, non-migratory songbirds that feed on insects, live in large family groups and breed at the same time of year. The breeding males of both species have striking blue feathers.

"Splendid and variegated fairy wrens are so similar in their habitat preferences and behaviour, we'd expect them to act as competitors," said Christina Masco, a graduate student from the University of Chicago who co-authored the study. "Instead, we've found stable,

"WE'VE FOUND
STABLE,
POSITIVE
RELATIONSHIPS
BETWEEN
INDIVIDUALS
OF THE TWO
SPECIES"

positive relationships between individuals of the two species."

The first clue came when the researchers played a recorded vocalisation of a wren from one species and noticed that birds from the other species would respond to the call and fly in to investigate. Subsequent experiments involved playing vocalisations from familiar and unfamiliar birds to simulate an intrusion into the wrens' territory.

Both splendid and variegated fairy wrens were able to recognise the songs of birds from either species that shared their territory and would respond non-aggressively. Songs of birds from entirely different species drew similar responses. But dominant males of both species responded aggressively to unfamiliar songs belonging to splendid and variegated wrens from other territories.

By forming and keeping these associations with another species, it's thought that the fairy wrens can better defend their nests from predators and their territories from rivals.

SPACE

'IMMIGRANT' ASTEROID FOUND IN JUPITER'S ORBIT

Meet the Solar System's first-known permanent immigrant. A team of international researchers have located an asteroid nestled in Jupiter's orbit that started life in another solar system.

Dubbed (514107) 2015 BZ509, or BZ for short, the asteroid was found in a retrograde orbit, meaning that it moves around the Sun in the opposite direction to the other planets.

When the team ran simulations to trace the location of BZ back to the birth of our Solar System, 4.5 billion years ago when the era of planet formation ended, they found the asteroid has always moved in this way. This means that BZ could not have been there originally and must have been captured from another system.

"Asteroid immigration from other star systems occurs because the Sun initially formed in a tightly-packed star cluster, where every star had its own system of planets and asteroids," said Dr Helena Morais of Brazil's Universidade Estadual Paulista, who took part in the research. "The close proximity of the stars, aided by the gravitational forces of the planets, help these systems attract, remove and capture asteroids from one another."

Understanding how and when BZ settled in the young Solar System could provide clues about the conditions when the planets were first being formed. It could offer insights into Earth's early environment and potentially the arrival of components necessary for the appearance of life on Earth.

The stellar nursery NGC 604 has closely packed star systems, and asteroid exchange is thought to be possible. BZ would have experienced similar conditions when it settled in our Solar System

THINGS WE LEARNT THIS MONTH

CHIMPANZEES' BEDS ARE CLEANER THAN OURS

This may not come as a surprise to parents of teenagers, but a study by North Carolina State University has found that the treetop beds that chimpanzees make each evening have far fewer bacteria, parasites and faecal particles than human beds.

WEEKEND LIE-INS CAN HELP YOU LIVE LONGER

Sleepy heads rejoice! Having a weekend lie-in to catch up on sleep could extend our lifetimes, researchers at the University of Oxford have found. Zzz.

SHARKS LIKE JAZZ

Researchers in Sydney who trained baby Port Jackson sharks to go to a feeding station each time they heard music have found they respond more positively to jazz than classical. Nice.

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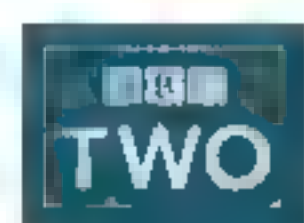
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"IS IT POSSIBLE TO BEAT JET LAG?"



DR MICHAEL MOSLEY



Michael is a science writer and broadcaster, who presents *Trust Me, I'm A Doctor* on BBC Two. His latest book is *The Clever Guts Diet* (£8.99, Short Books)



This summer, lots of people will be jetting off to exotic countries and passing through multiple time zones. I'll be one of them. The trouble is, I spend far too much of my life doing this, mainly while making documentaries. So I am, naturally, obsessed with jet lag.

Jet lag is caused by a mismatch between external time cues (the Sun is rising, it must be morning) and our internal, circadian clock. The circadian clock plays a vital role in regulating a range of things, such as your sleep/wake cycles, and which hormones get secreted and when. Jet lag, which messes with your circadian rhythm, can do some pretty awful things to your body and your brain. It not only makes you feel knackered, but lots of long-distance travel can trigger sleep disorders and encourage obesity.

New research suggests that one way it does this is via the microbiome, the one to two kilograms of microbes that live in your gut. To demonstrate the impact that jet lag can have on the microbiome, Dr Eran Elinav and Dr Eran Segal from the Weizmann Institute asked some of their students to fly across multiple

time zones. They were asked to collect a faeces sample before they got on the plane, another when their jet lag was particularly bad and a final one two weeks after that.

The researchers cultivated these samples and transferred the microbes into mice, specially raised to have bacteria-free guts. The impact was dramatic. As Elinav enthusiastically informed me, "the mice that received the microbes from jet-lagged students grew obese and developed diabetes. Those that were given bacteria from samples taken before or after the jet lag set in were unaffected."

The moral is, try to avoid flying across lots of time zones. But if you can't, what should you do? Well, since your gut bacteria seem to play a role in regulating your circadian rhythm, you could try, before you fly, changing mealtimes so they fit in with your new destination. If you are flying to the US, consider having breakfast five hours later than normal.

A University of Surrey team recently did this with 10 volunteers. They found that some of their circadian rhythms

were delayed by roughly five hours, suggesting that altering mealtimes had partially reset their body clocks.

Then there's melatonin. This hormone, produced by the pineal gland, helps prepare the body for sleep. While it's only available on prescription in the UK, you can buy it at any pharmacy in the US as a supplement. A Cochrane study (when it comes to evidence-based medicine they don't come much better) said: "Melatonin is remarkably effective in preventing or reducing jet lag, and occasional short-term use appears to be safe. It should be recommended to

adult travellers flying across five or more time zones, particularly in an easterly direction, and especially if they have experienced jet lag on previous journeys." I find it helpful, particularly on overnight flights and for the first few days in a new time zone.

I use light to adjust my internal clock, too. When I arrive at my destination after flying east, I avoid early morning light and seek out afternoon light for a couple of days. This is known as 'phase advancing'. When going west, I do the reverse. Anything to keep my microbiome happy! **F**

The microbiome seems to return to normal two weeks after a long-haul flight, but frequent flyers could find the disruptions become chronic.



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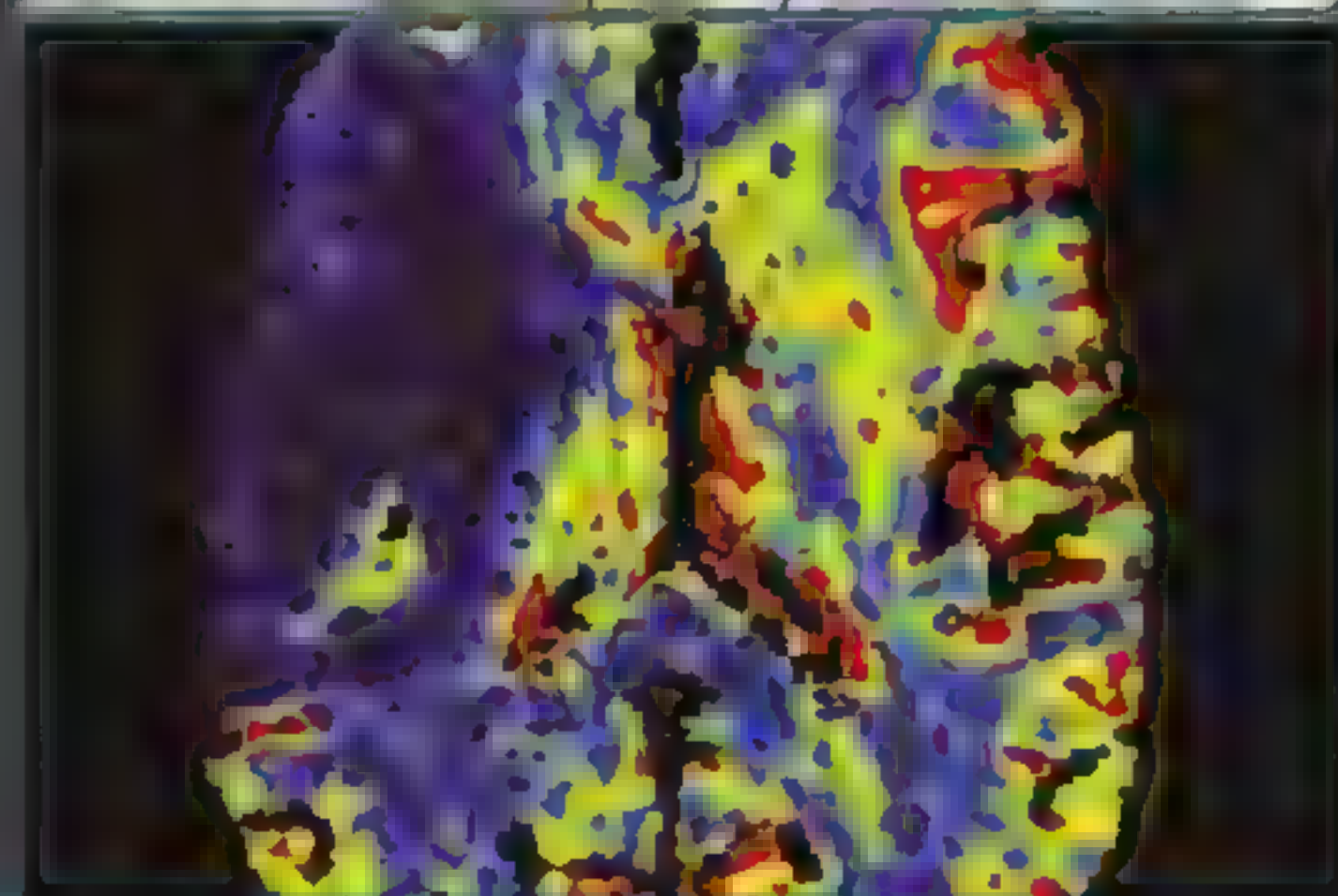
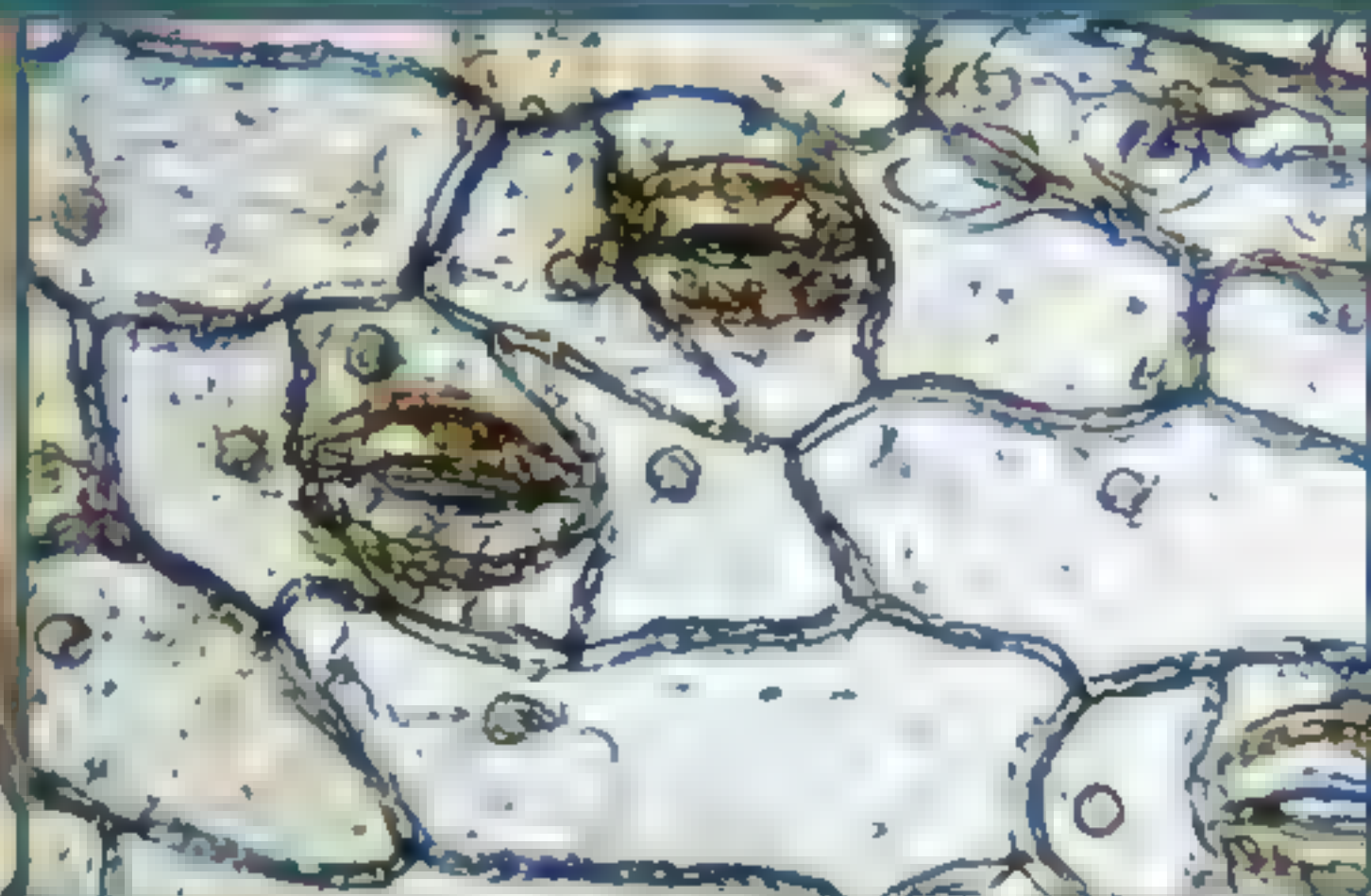
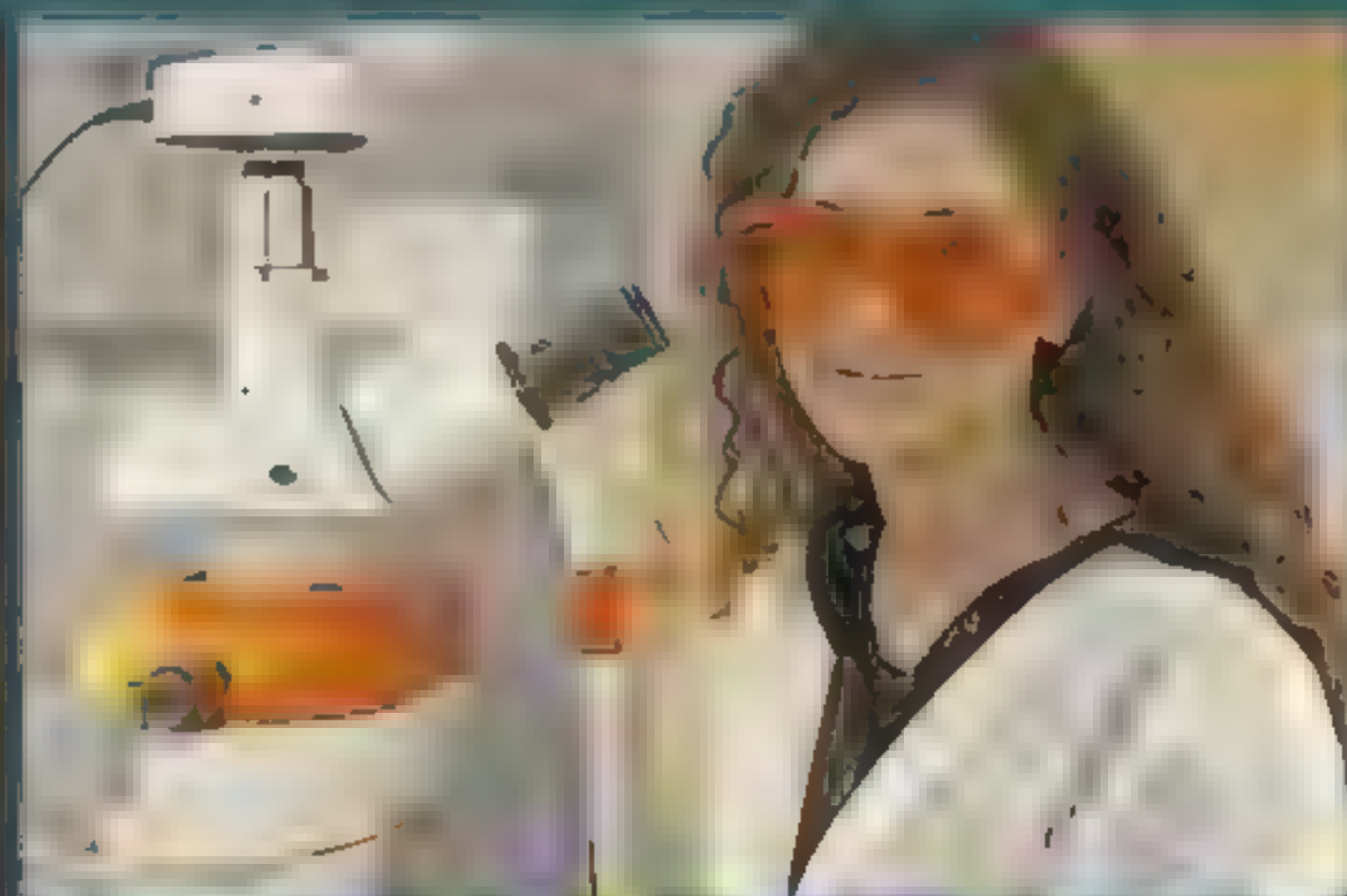
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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

JULY 2018

EDITED BY HELEN GLENNY



ADAPTIVE XBOX

Gaming controllers can be a barrier for many players, so Microsoft has developed the Xbox Adaptive Controller, a highly customisable solution for gamers with a broad range of disabilities.

The new controller features two large programmable buttons and 19 jacks that can be connected to a range of joysticks, buttons, switches and mounts, allowing gamers to personalise their setup. Microsoft claims it's the most flexible adaptive controller ever made by a major gaming company. Currently, it can be used to play Xbox One and Windows 10 PC games, and gamers can set up three profiles on their controllers, so

they don't need to re-program the set up for every new game.

Microsoft is considering rolling out several of the controller's new features in its other products. For example, symbols embossed onto one edge of the controller identify each port, so users don't have to turn the device around to find the right plug.

This project stems from the Gaming for Everyone initiative, which Microsoft launched in 2015 with the goal of engaging a broader range of Xbox players. The controller was also influenced by the work of Warfighter Engaged, a non-profit organisation that creates gaming devices for severely wounded war veterans.

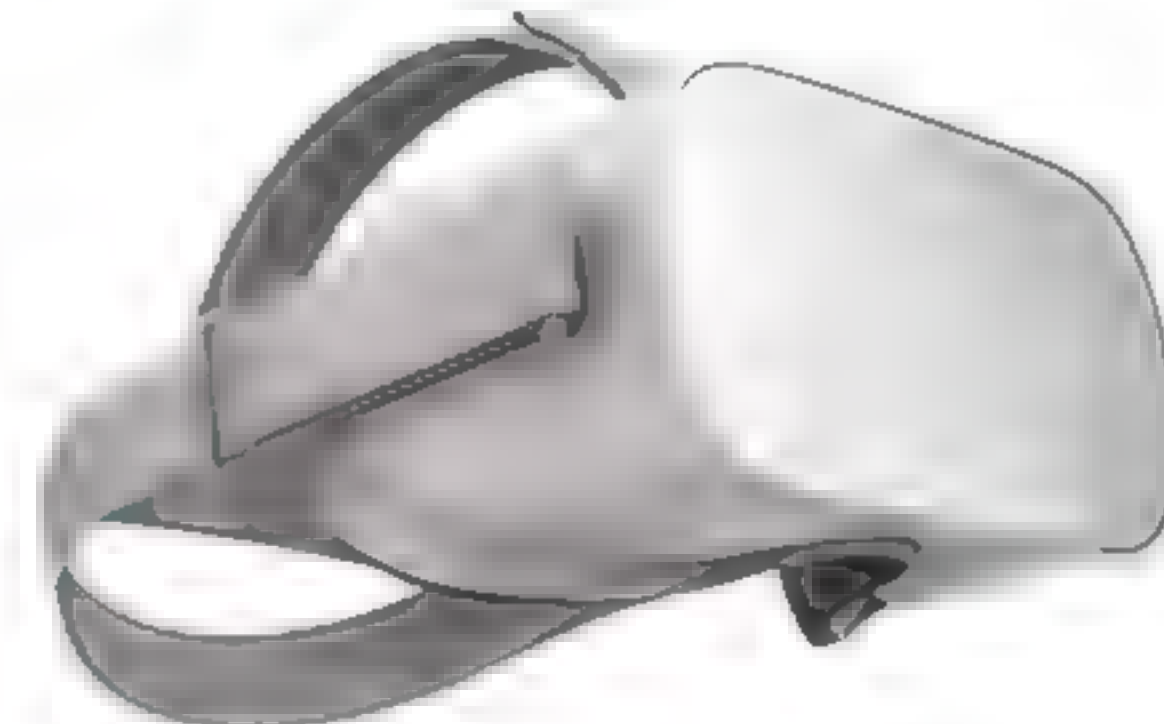
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[3]



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[6]



WANTED

[1]

EASY ON THE EAR

These lightweight, sweat-resistant wireless earbuds are designed specifically for sport. You can control them with a three-button remote and if you've got your boxing gloves on, you can use voice prompts for convenience.

Sennheiser CX Sport
£119, sennheiser.com

[2]

LAZY BONES

Wickedbone is the ultimate toy for energetic dogs with tired owners. You can direct the rolling bone-shaped robot with your smartphone, so you can play with your dog while motionless on the couch.

Wickedbone
AU\$89 (approx £50), cheerble.com

[3]

VR FOR EVERYONE

Oculus Go is all about practicality. You don't need a smartphone or a high-tech gaming PC as everything is contained in the headset. It requires minimal setup, so it could be the headset that brings VR to the masses.

Oculus Go
£199, oculus.com

[4]

ABOUT TIME

Want to mark an important event? Pull the pin on this Time Since Launch clock, and it'll record the days, hours, minutes and seconds since it took place, for up to 2,700 years. Just remember to replace the batteries every 40 years.

Time Since Launch
\$150, (approx £112) cwandt.com

[5]

NEED FOR SPEED

This all-wheel-drive electric longboard has a motor in each wheel, so you're not going to grind to halt riding up steep streets. It has a single-charge range of 35km (22 miles), regenerative braking and tops out at 37km/h (23mph).

Acton Blink Qu4tro
\$1,699 (approx £1,300), actonglobal.com

[6]

NECK SPEAKER

For a compromise between in-your-own-world headphones and a blaring sound system, try the Bose Neck Speaker. Slip it round your neck and it produces a cone of sound that concentrates the music in the wearer's listening space.

Bose SoundWear Companion Speaker
£259.95, bose.co.uk

PLAIN AND SIMPLE

In the rebellion against addictive tech, distraction-free smartphones are all the rage. While most look to cut down on features, the BllocZero18 takes a different approach. It's a full-featured phone but runs on an operating system that consolidates all your apps into a single timeline, called The Root.

All your in-app interactions, notifications and conversations, including Facebook Messenger, WhatsApp, Slack and more are combined into one continuous flow by The Root. The idea is to encourage users to use their phones more efficiently so whether you're booking flights or checking the weather, it all happens in one place.

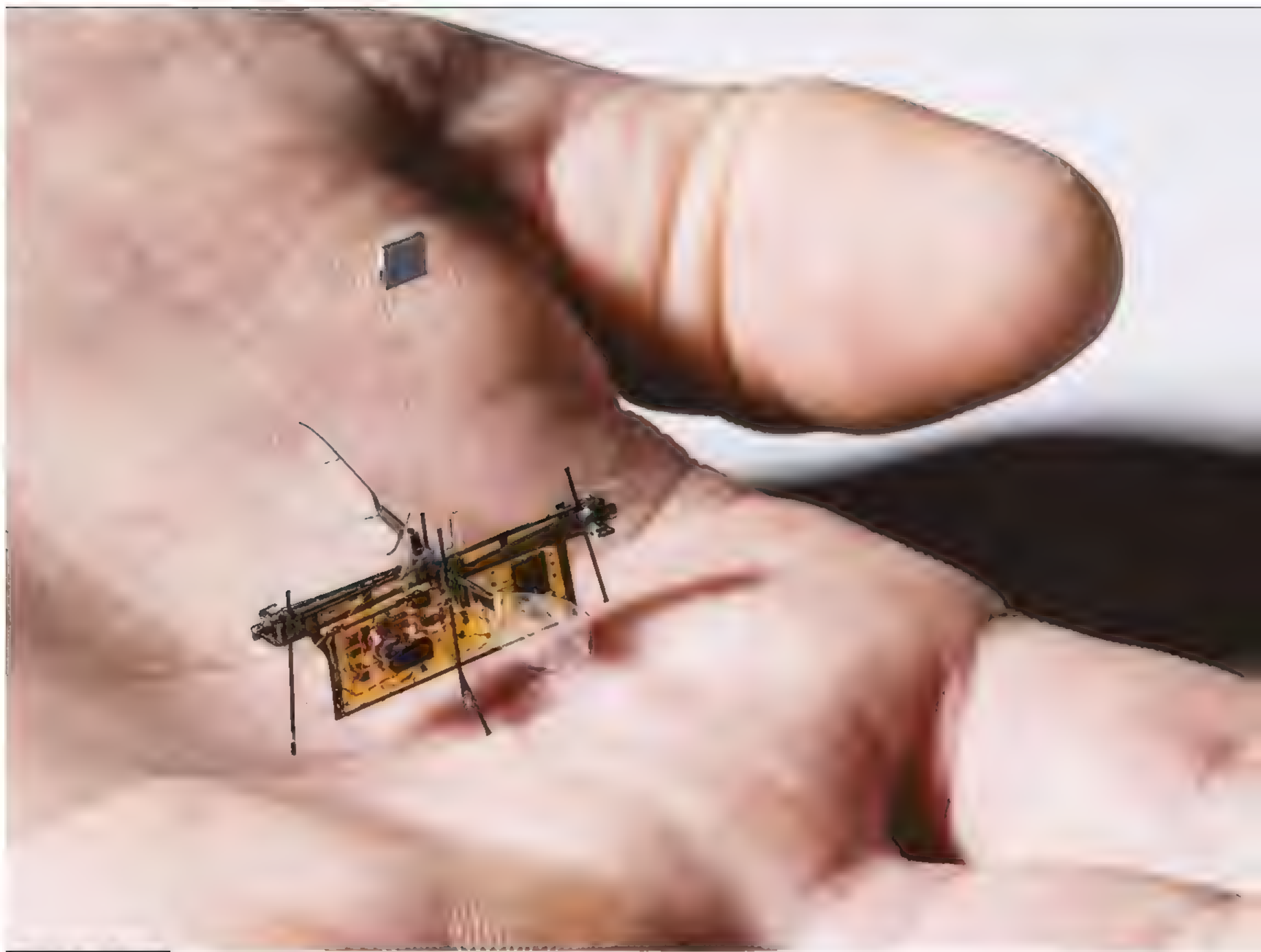
The BllocZero18's monochrome display is said to be less stimulating than colour to deter you from mindlessly scrolling. But the phone still packs a 13-megapixel camera that shoots in 4K and lets you view your pics and clips in colour when necessary.

Thanks to the monochrome display, the apps work incredibly fast and the phone is comparatively power-efficient, giving you a longer performance for a single charge. For people who don't want to compromise on function, this might be a good start to kicking your smartphone addiction.

BllocZero18

€359 (approx. £315), blloc.com





ROBOTICS

ROBOFLY TAKES OFF

Power and lift are the flies in the ointment when it comes to building robotic insects

Creating tiny flying robot insects is a harder task than you'd imagine; they're too small to carry propellers and the electronics they need for power weigh them down. But engineers at the University of Washington have successfully flown their first wireless robot fly.

The RoboFly uses tiny wings to take off and stay aloft, which is where it runs into problems. Wing flapping is an energy-intensive process and batteries are heavy. So instead, the engineers power the tiny robot by pointing an invisible laser beam at a photovoltaic cell attached to the RoboFly, which converts laser light into energy.

"It was the most efficient way to quickly transmit a lot of power to RoboFly without adding much weight," said co-creator Shyam Gollakota, an associate professor in the Paul G Allen School of Computer Science and Engineering.

The laser alone doesn't provide enough energy for lift-off though, so the team installed a circuit that boosts the energy coming from the photovoltaic cell. They also added a brain, a microcontroller that adjusts the rate at which the wings flap.

Right now the RoboFly can only take off and land, but researchers hope this invention will pave the way for more useful RoboFlies. "I'd like to make one that finds methane leaks," said co-creator Sawyer Fuller, of the University of Washington's Department of Mechanical Engineering. "You could buy a suitcase full of them, open it up, and they'd fly around your building looking for gas coming out of leaky pipes. If these robots can make it easy to find leaks, the leaks are more likely to be patched up, which will reduce greenhouse emissions. This is inspired by real flies, which are really good at flying around looking for smelly things."

TECHNOLOGY

FACIAL RECOGNITION DETECTS DISTRACTED STUDENTS

Three cameras have been installed above a blackboard at Hangzhou Number 11 High School in China to identify students who aren't focussed on their lessons.

It's called a 'smart classroom behaviour management system', or 'Smart Eye'. The cameras scan students every 30 seconds and recognise seven facial expressions: neutral, happy, sad, disappointed, angry, scared and surprised. It can also identify actions such as reading, writing or sleeping. If the system spots a student that isn't paying attention, it sends a notification to the teacher. Right now, it's only been installed in one classroom, but it will be deployed across the school before autumn.

Critics of the Smart Eye system have raised questions about privacy, but headmaster Ni Ziyuan claims that it's equivalent to having a teaching assistant in the classroom and will improve the quality of teaching. He adds that the system only records the students' movements, rather than filming them during their lessons.

This is the latest civilian surveillance programme to be rolled out in China. Facial recognition technology has already been installed at train stations and pop concerts to identify law-breakers, in university lectures to test interest levels, and at cash machines and fast-food restaurants.



MARK STONE/ UNIVERSITY OF WASHINGTON, SHUTTERSTOCK, GETTY

TECH BYTES

MOO-TOOTH TRACKERS

Livestock Labs have implanted bio-monitors, called EmbediVets, under the skin of cows to help farmers spot disease. CEO Tim Cannon knows how it feels: he tested the tech by embedding one under his own skin before they were inserted in cows.



CALIFORNIA HOMES MUST HAVE SOLAR

The California Energy Commission now requires that all new homes built from 2020 onwards must have solar panels installed. It's part of state law that requires California to generate half its power from renewables by 2030, a target they're likely to hit well ahead of schedule.

WOMEN'S WORK

Research shows that jobs typically held by women are less likely to be taken over by robots. Women are overrepresented in roles that require high levels of social skills and empathy, and these are more difficult to automate. Men replaced by robots can stay home and do the housework.



ON TEST: ULTRA HD TVS

With the 2018 World Cup just a few sleeps away, DANIEL BENNETT treats his eyes to the new breed of affordable 4K TVs

There's never been a better time to make the leap to Ultra HD. The likes of David Attenborough, Mo Salah and Meghan Markle have all been the subject of 4K broadcasts this year, while streaming services offer almost all new additions to their library in an Ultra HD format. In the meantime, most

manufacturers have been phasing out the HD TVs (1080p) that usually occupy the affordable end of the shop, replacing them with Ultra HD sets. With more excuses than ever to upgrade (including a big excuse just around the corner), we take a look at the 'affordable' end of the market to see what's on offer.

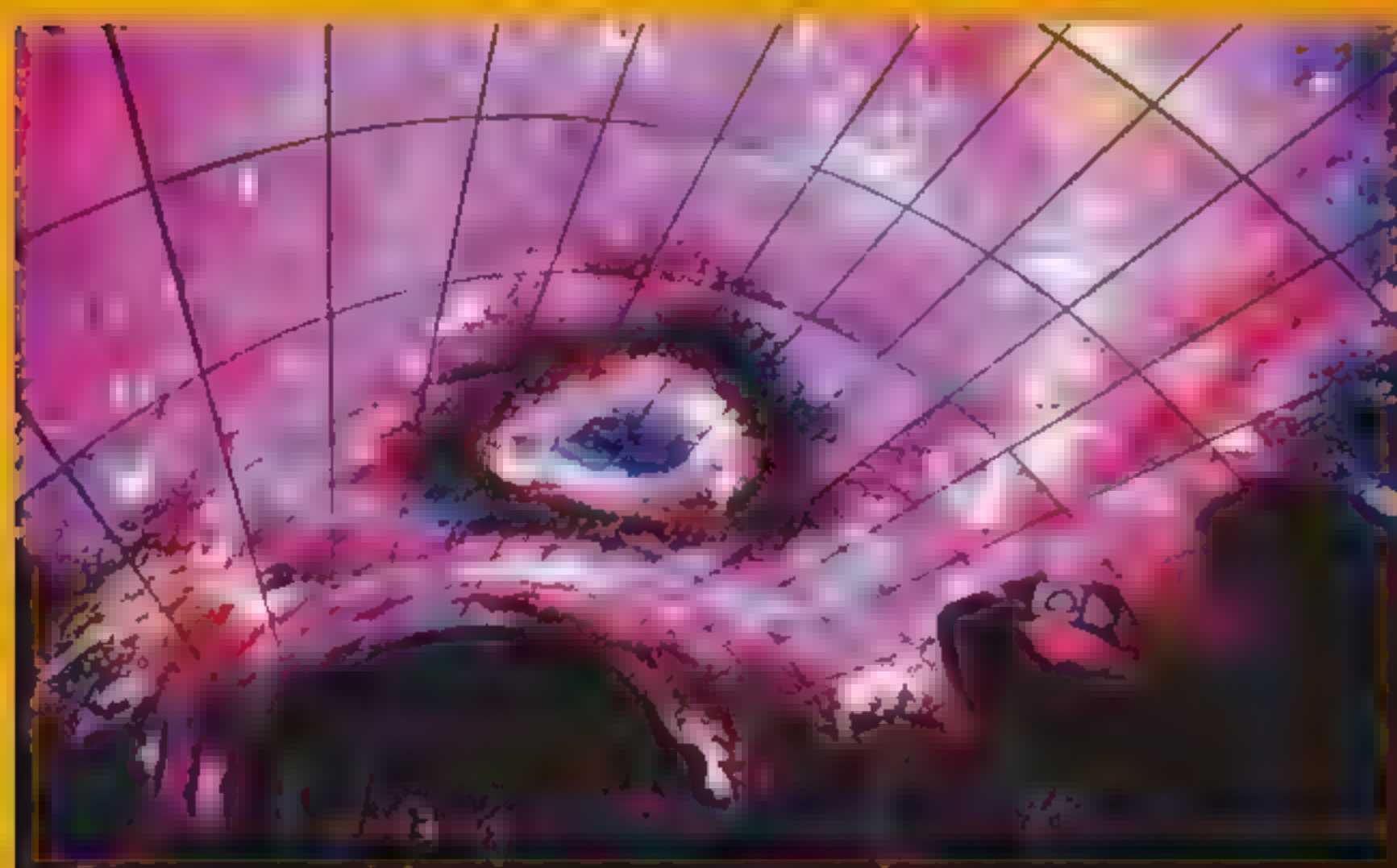


WHAT YOU NEED TO KNOW

These days you need a translator just to understand all the jargon that modern TVs throw at you. To be blunt, you can ignore most of it. But there are a few things you should look for...

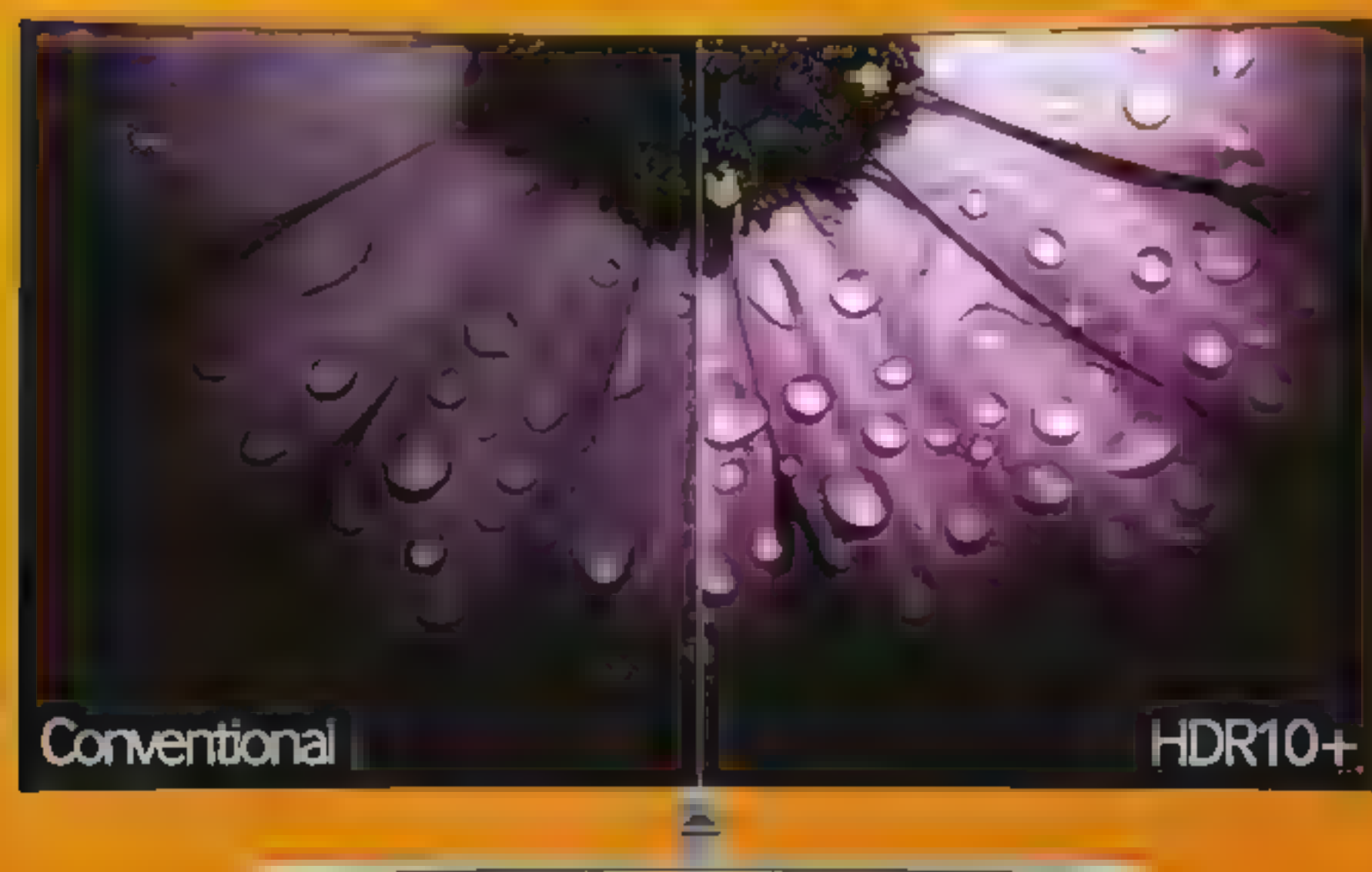
OLED ↓

For out-and-out picture quality, OLEDs provide the greatest fidelity. These TV panels rely on organic crystals which, when they meet electricity, light up. This removes the need for a backlight – these are required in LED or LCD sets, but they bleach away some of the more delicate colours and contrasts. No backlight also means the panel can be thinner. The only drawback to an OLED is its price, costing around two times more than other panels.



HDR ↓

High Dynamic Range (HDR) makes a big difference to picture quality. On an LED or LCD television it means that the backlight can be darkened or brightened where needed, for example behind blacks and greys. HDR mode will typically make brighter parts of the picture look, well, brighter, and blacker areas look darker. Blues and greens will come out richer and more life-like, while greys and shadowy images will look more nuanced. HDR TV works best with content made for it, which is primarily being released on the likes of Netflix and Amazon Prime, but most sets will try to use it to improve standard content.



↑ SMART ATTACK

All TVs now come with 'smart' features, but not all are made equal. Each brand will have its own TV operating system. None are perfect, and all come with their own quirks, so it's worth visiting a shop and having a play with the interfaces before committing. It's also important to check a TV is compatible with the services you subscribe to and like to use most. That said, if you have a set-top box and a games console, you're unlikely to need most of these settings, and should therefore prioritise raw image quality.



↑ WHERE TO GET 4K TV

Most streaming services are now putting out their latest films and series in 4K quality. Broadcast TV is slower to catch up, but SKY Q and Virgin both offer box sets and films in 4K, as well as sport like Formula 1 and the Champions League. The World Cup this year is being filmed in 4K, but no UK channel has yet confirmed that it'll actually be broadcasting games in 4K. The BBC was trialling 4K iPlayer earlier in the year, so we're holding out our hopes for that.

SONY XF90

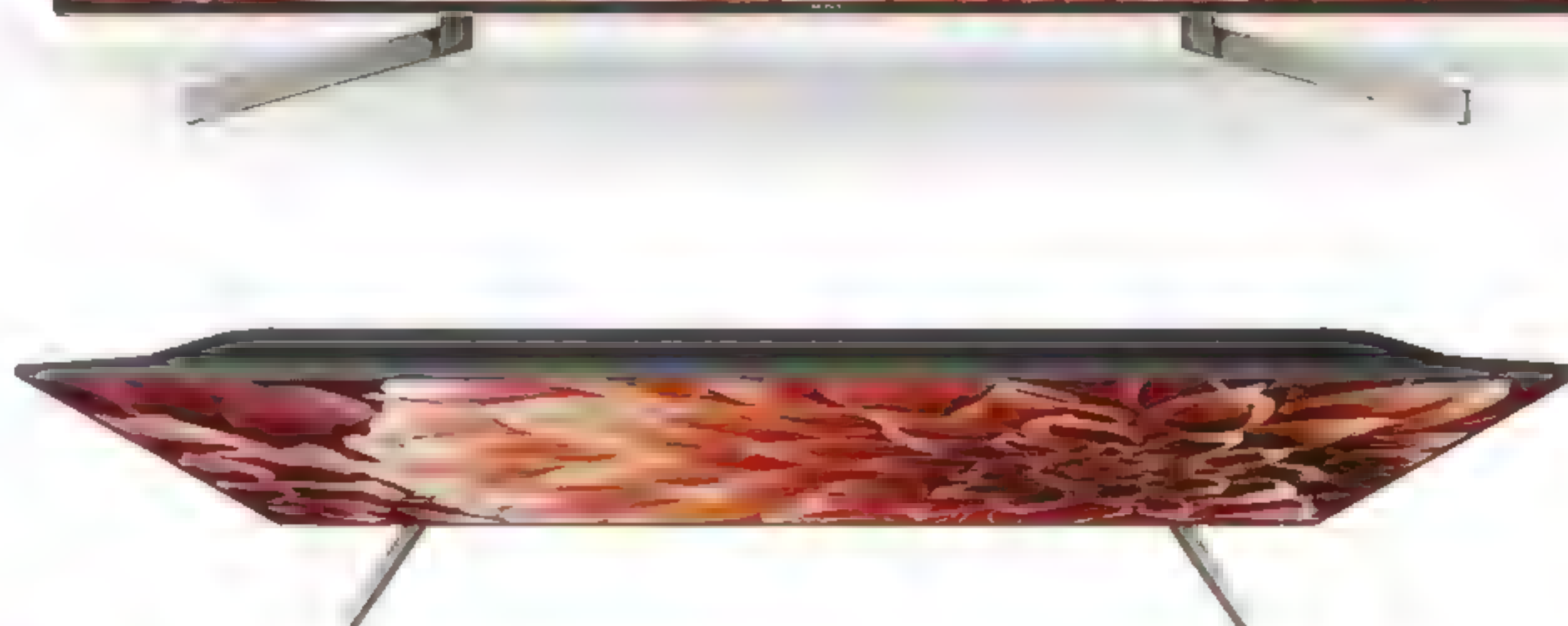
Out of the box, the Sony is the plumpest set of the lot. The extra girth is hiding a direct-lit LED LCD display with full array dimming. In plain English, the TV's LED backlight sits behind the LCD screen, dimming dark parts of the picture to create better contrast. This tech does a great job of getting close to LG's OLED colour fidelity, at half the price. The XF90 also uses Sony's new X1 Extreme video processor, which did the most convincing job of upgrading HD TV content to 4K resolution. In fact, whatever the source of content, be it Blu-ray, DVD, or non-HDR, the XF90 did an admirable job of making sure the picture was consistently brilliant.

Despite the broad profile, the XF90 cuts an elegant silhouette front-on. The feet are little on the wide side, so check your measurements before buying. The Sony Android TV interface is a mixed bag. It looks slick, but the interface is slower and less intuitive than the competition. The upside is that the XF90 will play extremely well with Android phones, and offers probably the broadest spectrum of compatible apps of the TVs. In terms of picture quality, this set punches above its price range, though its interface and 'smart' features lag behind.

Picture quality 9 Value for money 11

Design 8 Interface 7 Overall 9

£1,200 Sony



LG C8 OLED

The C8 is a stunner. It delivers some of the best home cinema visuals we've ever seen. The blacks are deep, and the colours are rich and saturated. With 4K HDR content, there's a granularity and subtlety in the detail that makes everything feel eerily lifelike. In the past, older OLED

models struggled with motion, in other words football, and anything less than a 4K source. LG's new A9 processor seems to have remedied both issues, with sport and gaming looking flawless while lesser definition sources are elevated to a high standard. That said, you will have to play around with some of the settings to find your sweet spot. None of this should come as a surprise, considering the price tag. There's no getting away from the fact that this set, right now, is almost three times what most of us would spend on a TV.

The C8's new brains also means it can be controlled by speech (although we never felt compelled to use this feature) and it will play nice with both Amazon Alexa and Google Assistant. The interface is easy to use and lightning quick, but looks pretty basic in comparison to the C8's sharp outward aesthetics. There's often not a lot of leeway as far as TV design goes, but a slab of 2p-thick glass sat atop a brushed metal plinth is one of the best looks we've ever seen. Just protect it from your clumsier mates.

Picture quality 10 Value for money 6

Design 9 Interface 8 Overall 9

£3,000 LG





SAMSUNG NU8500

The NU8500 has the 'wow-factor'. The curved display is framed with the thinnest of bezels, making it seem almost edgeless; the user interface is quick to navigate; and the slimline remote does away with all those buttons you never use. Despite the reductionist design there are many features, including a Universal Guide that pulls together content from across broadcast and streaming services, a smart home hub from which you can control any compatible gadgets, and a Steam link that streams games from your PC to your TV. It was only when we tested out the picture quality in a number of scenarios that we felt the NU8500 was a little lacking. Motion was a particular problem, with rapid action (jolty cameras or fast-moving balls) getting rough treatment. The NU8500 is also edge-lit (it's how it's so breathtakingly thin) which means that the colours felt lacking in places. That said, the HDR+ mode seemed to have the greatest impact on the picture quality, offering the best performance of the screens when it came to boosting older films and TV.

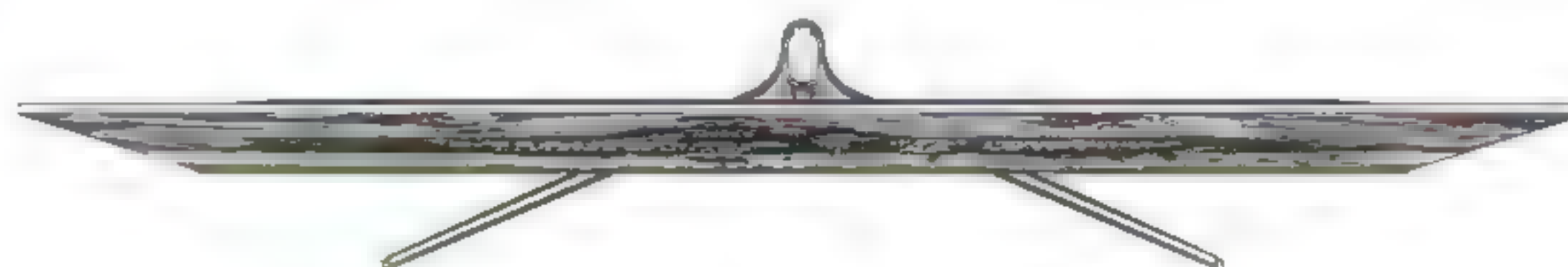
Picture quality 7 **Value for money** 7
Design 9 **Interface** 9 **Overall** 8
 £1,609, samsung.com



HISENSE U7A

The Hisense U7A is the best kind of bargain: one that nobody will know about until you tell them. For one, the design and finish belies its price tag: the bezel is almost as thin as that of the Samsung NU8500, and it's just as slender from the side. Powered up, the picture is sharp and smooth, though perhaps not as nuanced or vibrant as the other three sets tested. The HDR10 support uplifts content of all types, but it's not as marked a difference as seen on the other TVs. As befits the official TV of the World Cup, the U7A handles fast movement, removing judder while retaining detail.

The smart system is not as flashy as the others, but it's easy to navigate and comes with all the important apps and services. There's even a clever feature that notices when you're tuning into sports, and offers to flick the TV into its sports video and audio presets. Our only major issue with the TV was that only two out of the four HDMI sockets allow for 60Hz, which means if you've got a games console, a set-top box that can handle 4K, and an Ultra HD Blu-ray player, you'll be visiting the back of the TV more often than you'd like.



VERDICT

There was remarkably little to fault with all four sets. Tech companies are getting smarter and making sure all your content looks great – no matter what the quality of the source. In all four sets, the image standard was high. For us, the best balance between price and image fidelity was Sony's XF90, but that's based on the idea

that'd we'd be using it with a set-top box and games console in place of its built-in interface. LG's OLED shows how good Ultra HD can be, the Hisense demonstrates that affordable doesn't mean missing out on quality, and Samsung leads the way in terms of its smart package. Bring out the popcorn.

Picture quality 7
Value for money 10
Design 8 **Interface** 8
Overall 8
 £603, hisense.com



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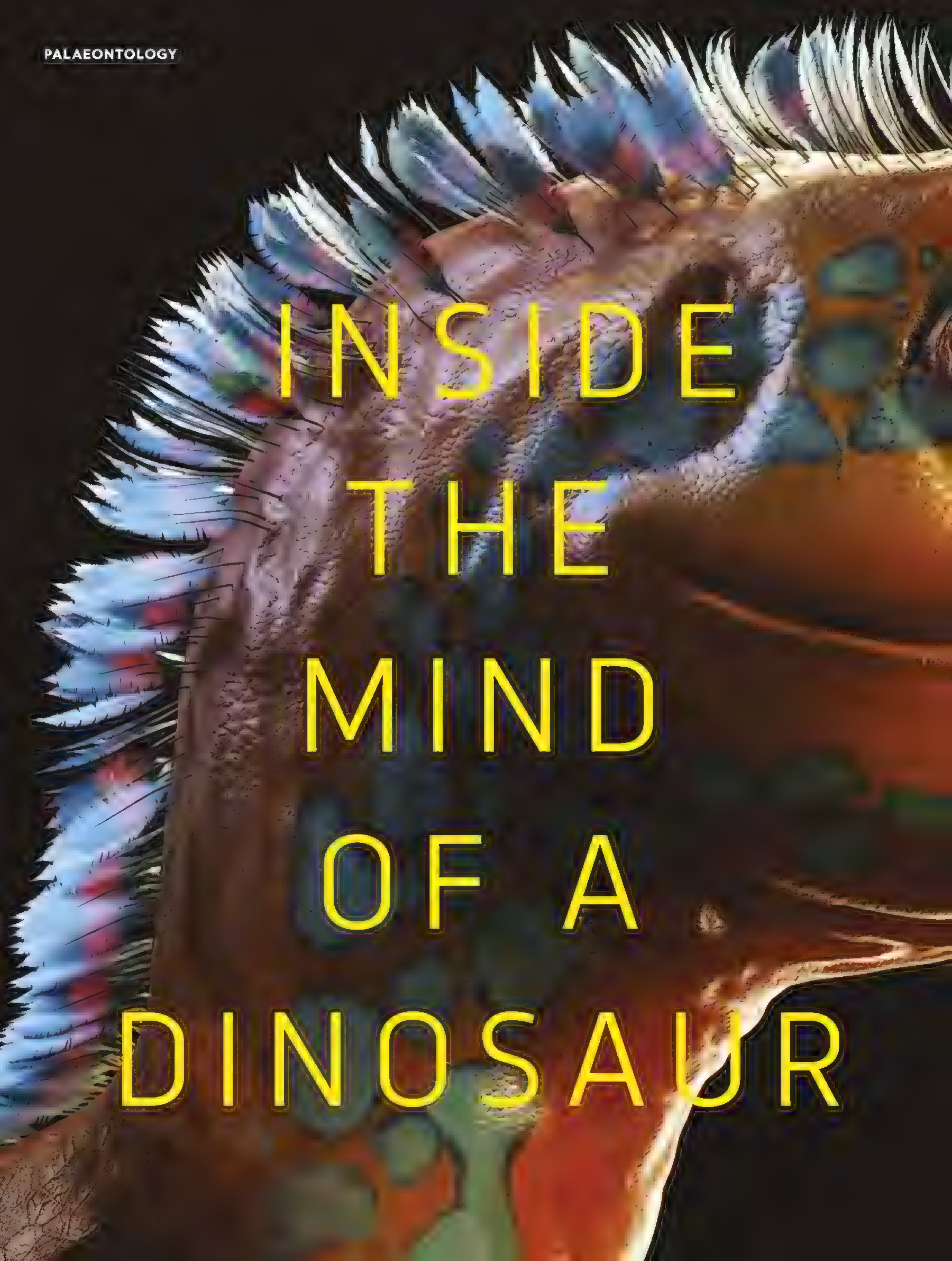
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PALAEONTOLOGY



INSIDE THE MIND OF A DINOSAUR



ILLUSTRATION: MAJID TORCH

Rather than being slow, lumbering and a bit stupid, dinosaurs were smart and nimble-brained – just ask the palaeontologists who are peering deep inside the fossilised skulls of these prehistoric animals

WORDS: DR STEPHEN BRUSATTE

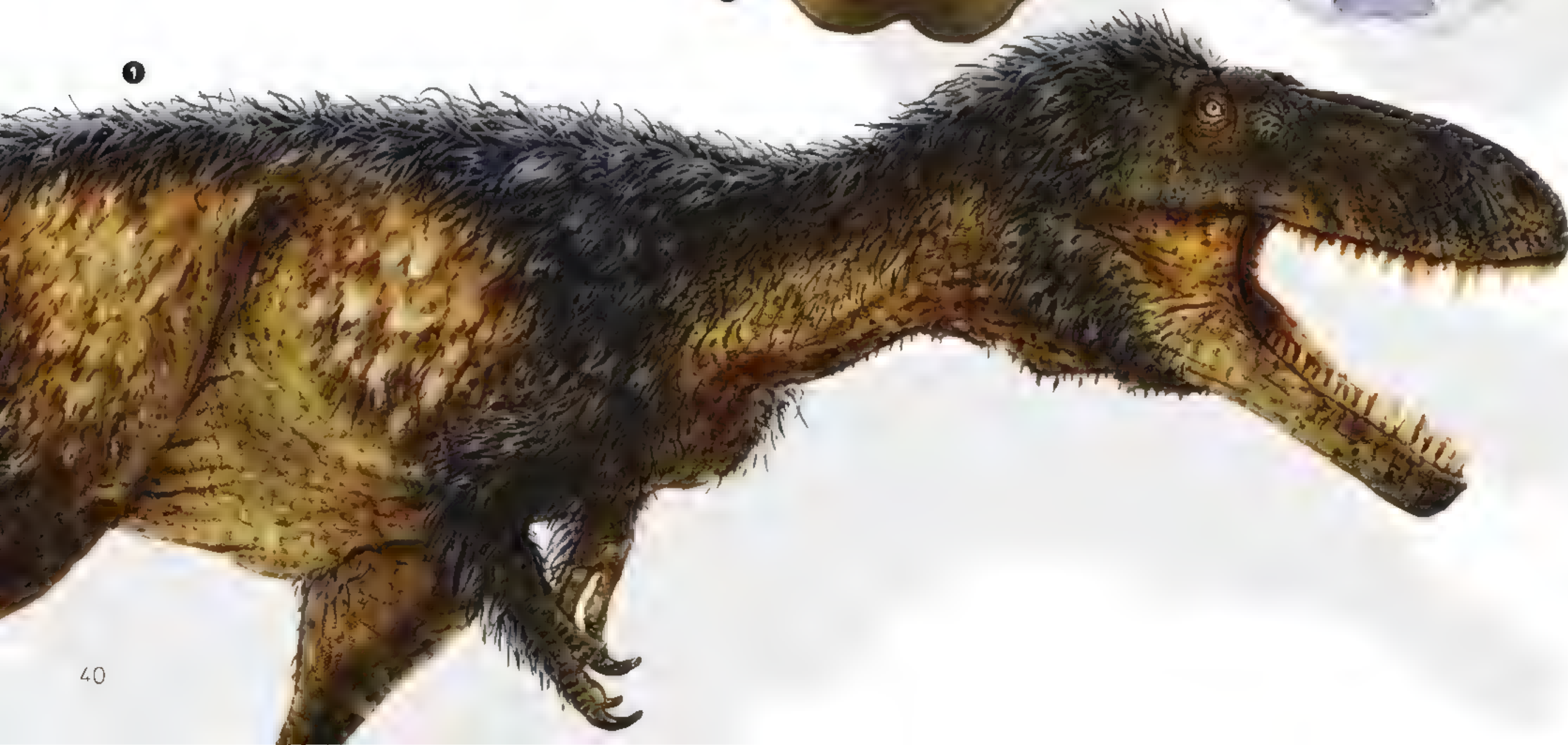
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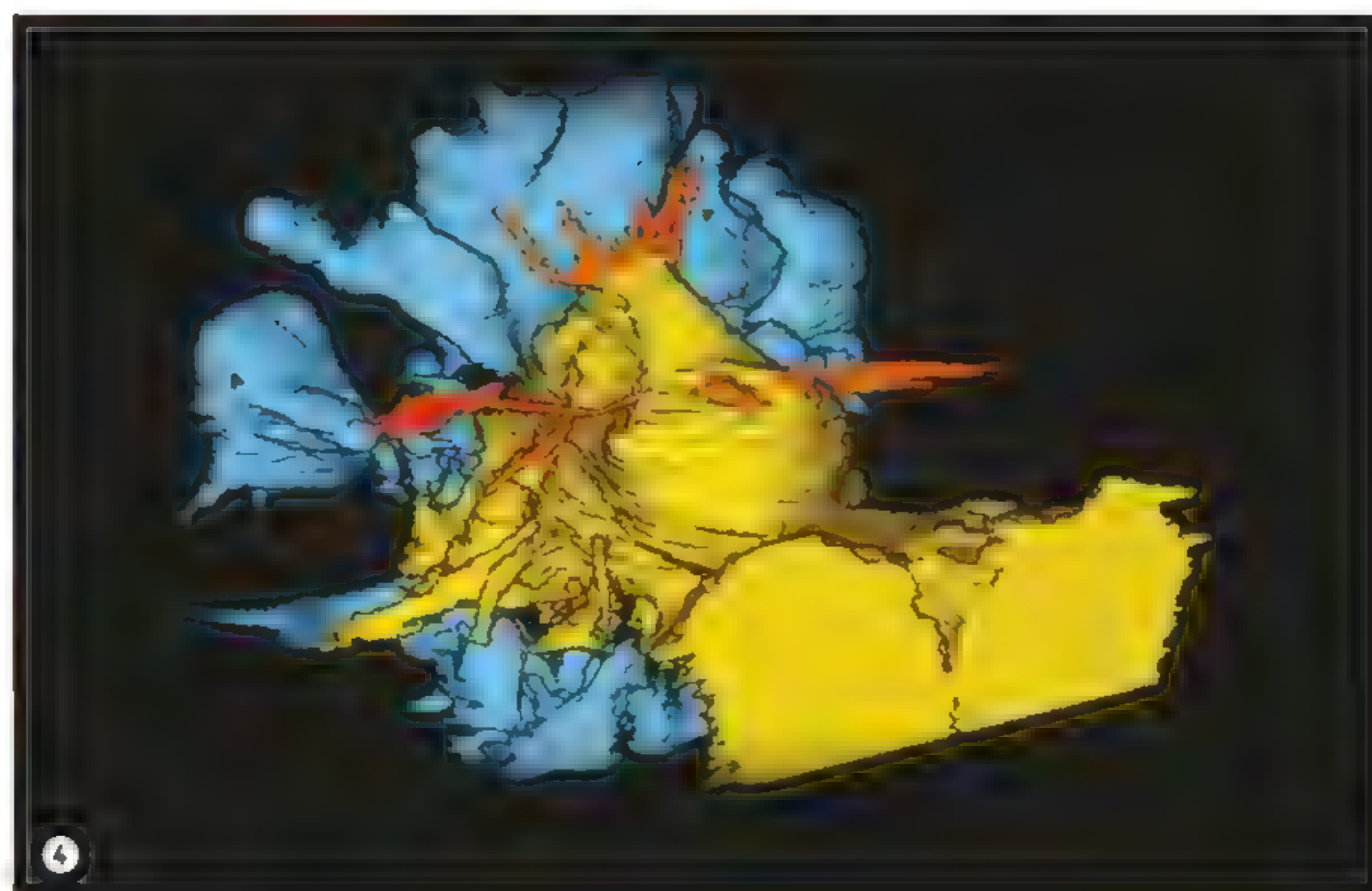
few years ago, as I loitered in the lobby of a high-rise hotel in Berlin, a man tapped me on the shoulder. In his thick Russian accent, he ushered me into the lift and up to his room. From a duffel bag,

he pulled out an ornately coloured cardboard box and handed it to me. I slowly opened the lid. Inside was a grapefruit-sized lump of petrified bone, which I recognised as the back end of a dinosaur skull. "Be careful with the fossil, but be even more careful with the box. This is Soviet box. They don't make them like this any more," he said with a mischievous grin, as he pulled out a bottle of cognac to toast the successful handover.

The man was no secret agent. He was Alexander Averianov, one of Russia's leading palaeontologists and a fellow dinosaur hunter. Nearly a decade before he led an expedition to Uzbekistan's Kyzylkum Desert, a barren expanse that yields some of the world's best Cretaceous-aged fossils. While there, someone on his crew plucked the skull from the sand dunes and safely packed it in the box, where it sat for several years as Averianov tried to make sense of it. He could tell it was the fused mass of bones that surrounded the brain and ear, but wasn't sure what type of dinosaur it belonged to, much less how it might have behaved and interacted with its environment. To figure that out, he would somehow need to see inside the skull: to look at the brain.

This is why he gave the boxed fossil to me, so I could take it to my lab at the University of Edinburgh and analyse it with a computed tomography (CT) scanner. CT scanning – the same technique employed by medical doctors – has become as indispensable to palaeontologists as rock hammers and chisels. By scanning dinosaur skulls, we can literally see





"Be careful with the fossil, but be even more careful with the box. This is Soviet box. They don't make them like this any more"

inside them and visualise the brains and other rarely fossilised internal structures that powered the intelligence and sensory prowess of these long-dead animals. This helps us understand dinosaurs as living, thinking, moving, evolving creatures, in a way that previous generations never could.

SKULL SCANNING

Back in 1912, after the first skeletons of *Tyrannosaurus rex* were discovered, scientists were desperate to understand how such a humongous animal actually lived. The man who named *T. rex*, Henry Fairfield Osborn, knew that the brain held the key. Brain tissue decays quickly after an animal dies, so Osborn conceded that a real dinosaur brain could never survive for millions of years. But perhaps if he could peer into the brain cavity – the space the brain once occupied inside the skull – he could get a sense of the size, shape and dimensions of the brain.

① *Timurlengia euotica* had a similar brain to the *T. rex*, but was only about the size of a horse

② *T. euotica* fossil that was delivered to Stephen Brusatte in a Soviet-era box. From left to right: fossilised braincase (the hole is where the spinal cord enters the brain); CT scan of the braincase, showing the brain, inner ears and sinuses inside the bone; the brain, inner ears and nerves (rear view); brain, inner ears, and nerves (side view)

③ *T. euotica* fossil being examined in a CT scanner

④ CT scan of the brain and sinus cavity of a *T. rex*

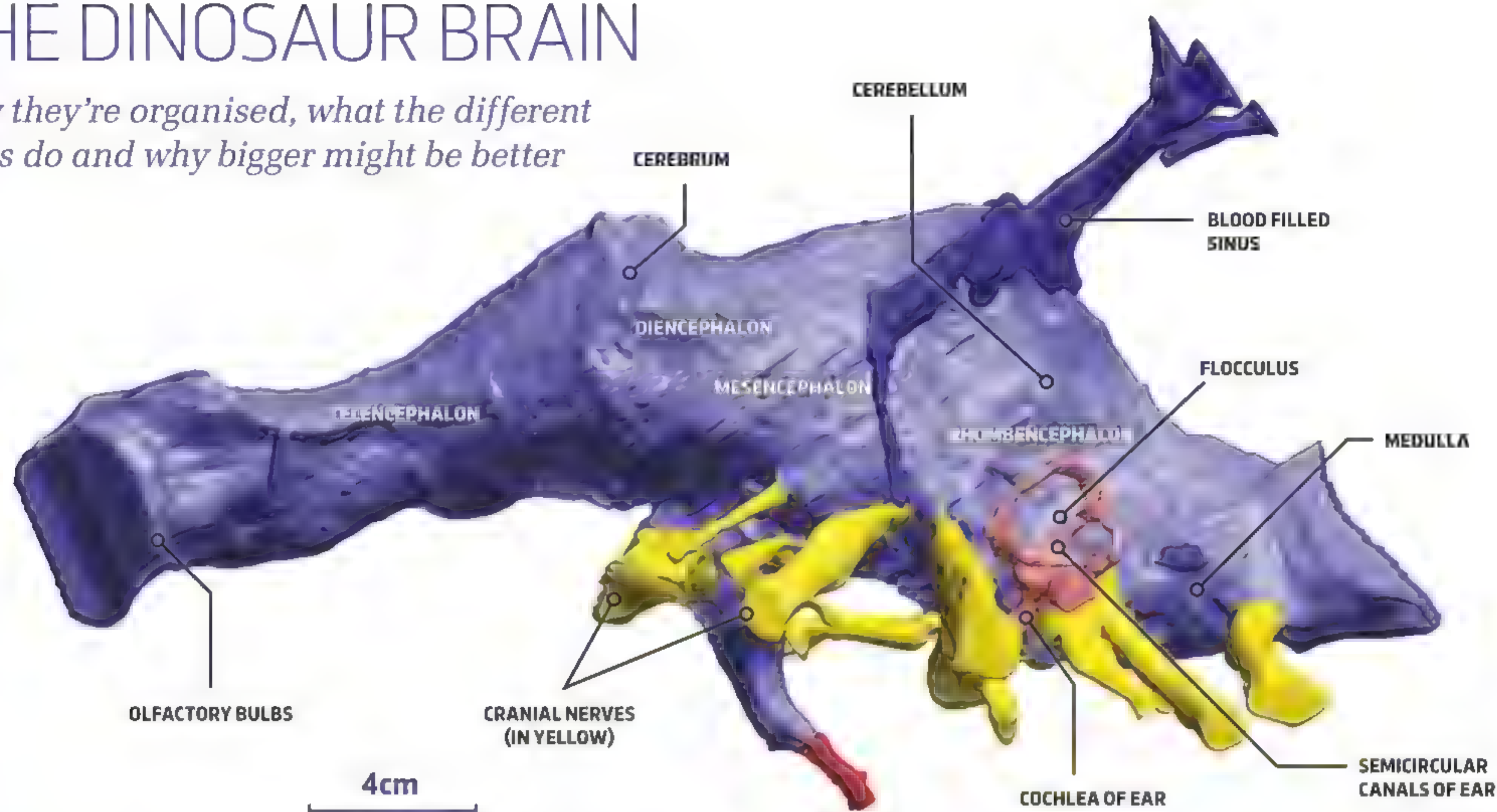
This, however, raised another problem. He could think of only one way to access the brain cavity, so he sawed open a skull of *T. rex*, permanently damaging it – a sacrifice in the name of science.

Not many other scientists had the nerve to cut up their fossils, so for the next several decades there was little research on dinosaur brains. Every once in a while, palaeontologists would find so-called 'natural endocasts': mud or sand that had filled the brain cavity, hardened to stone and then broken free. These were enough for Dr Harry Jerison and Dr James Hopson – two pioneers in the field – to argue that dinosaurs had fairly typical reptilian brains. But they couldn't say much more than that.

Then, beginning in the 1990s, CT scanning changed the game. CT scans are nothing more than X-rays, taken from many angles. If you stick an object in a CT scanner – whether it be a human body or a dinosaur fossil – the X-rays will pass through the object in an orderly manner, and then a computer will combine them into a series of two-dimensional slices. Each slice looks like a traditional X-ray image, of the sort you get at hospital when you break a bone or sprain a ligament. Like the X-ray images we're familiar with, the CT scan slices pick up density differences between materials, so bone shows up as ●

THE DINOSAUR BRAIN

How they're organised, what the different parts do and why bigger might be better



Dinosaur brains are long and tubular, as can be seen in the *T. rex* brain above. The largest region is usually the telencephalon, comprised principally of the left and right cerebral hemispheres: the seat of intelligence and sensory functions. At the front of the telencephalon are the olfactory bulbs that control the sense of smell, and behind it are the optic lobes of the diencephalon that power vision. A small midbrain region (mesencephalon) separates the diencephalon from the hindbrain (rhombencephalon). The rhombencephalon is further divided into the cerebellum, which plays a role in motor function, and the medulla, from which emerge the cranial nerves that control breathing, heart rate, blood pressure and other involuntary functions. A lobe of the cerebellum called the flocculus emerges laterally; it helps regulate eye, neck and head movements.

On the sides of the brain are the inner ears, which consist of the

pretzel-shaped semicircular canals that are filled with fluid to help regulate balance and head stabilisation. Beneath are the long cochlea, which control hearing. A number of air-filled sinuses emanating from the inner ear surround the sides of the brain, possibly helping to cool the brain or to enhance hearing. Other blood-filled sinuses cushion the sides and top of the brain.

The size of the brain can be used to estimate intelligence. Although measuring intelligence is riddled with uncertainties, there is a straightforward measure to roughly compare the intelligence of different animals: the encephalisation quotient (EQ). It's basically a measure of the relative size of the brain compared to the size of the body. Large animals usually have larger brains than smaller animals, even if they're not more intelligent, so the larger the EQ, the bigger the brain is relative to its expected value for the animal's size, and thus the more intelligent the animal is considered to be.

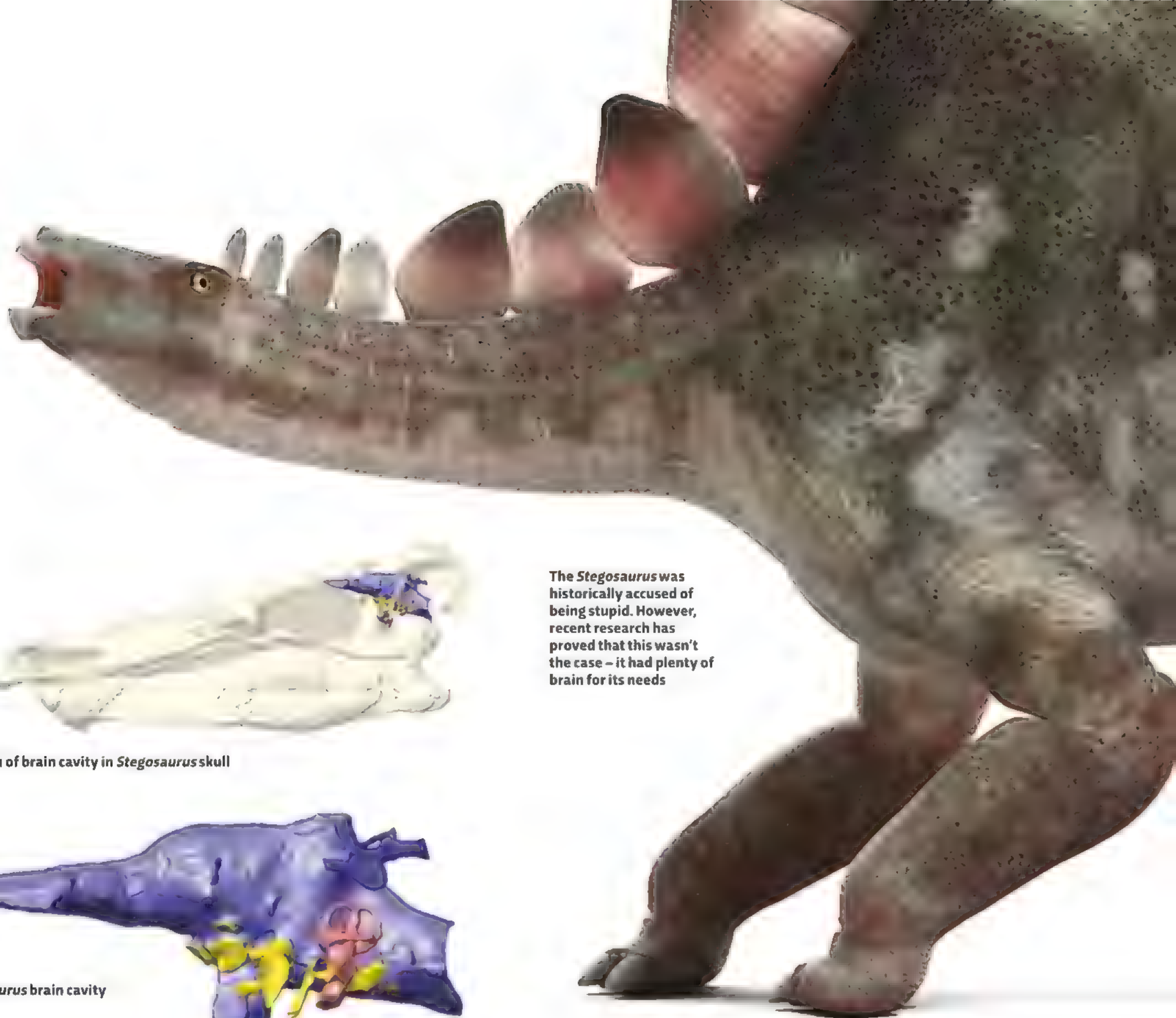
• a different greyscale colour to air or sand or mud. The series of CT slices is essentially a flipbook of images, which specialised software can assemble into a digital 3D model of the entire object that was scanned. Thus, the scan allows palaeontologists to see inside a fossil without cutting it open, the same way it permits a doctor to visualise the details of our internal anatomy without needing to do surgery.

CT scanning revolutionised palaeontology just as it did medicine. Now, scientists can simply put dinosaur skulls in a scanner and generate digital models of the filled-in brain cavity, inner ear, blood vessels, nerves and sinuses. It's non-invasive, relatively inexpensive and can be done using the same equipment found in almost any hospital. Nowadays, palaeontologists have become so accustomed to CT scanning that many of us have bespoke scanners in our labs or even use synchrotron particle accelerators to generate the high energies needed to scan sub-micron-sized details of the tiniest fossils.

ALL BRAWN, NO BRAIN?

The oldest dinosaurs, which lived during the Triassic Period (around 230 million years ago), had small and fairly primitive brains that were not too different from those of other reptiles. Some plant-eating dinosaurs retained these rudimentary brains, including the famous plate-backed *Stegosaurus*, which lived during the Jurassic Period (around 150 million years ago).

Stegosaurus was a popular punchline in the dinosaur books that I read as a kid, with its supposedly



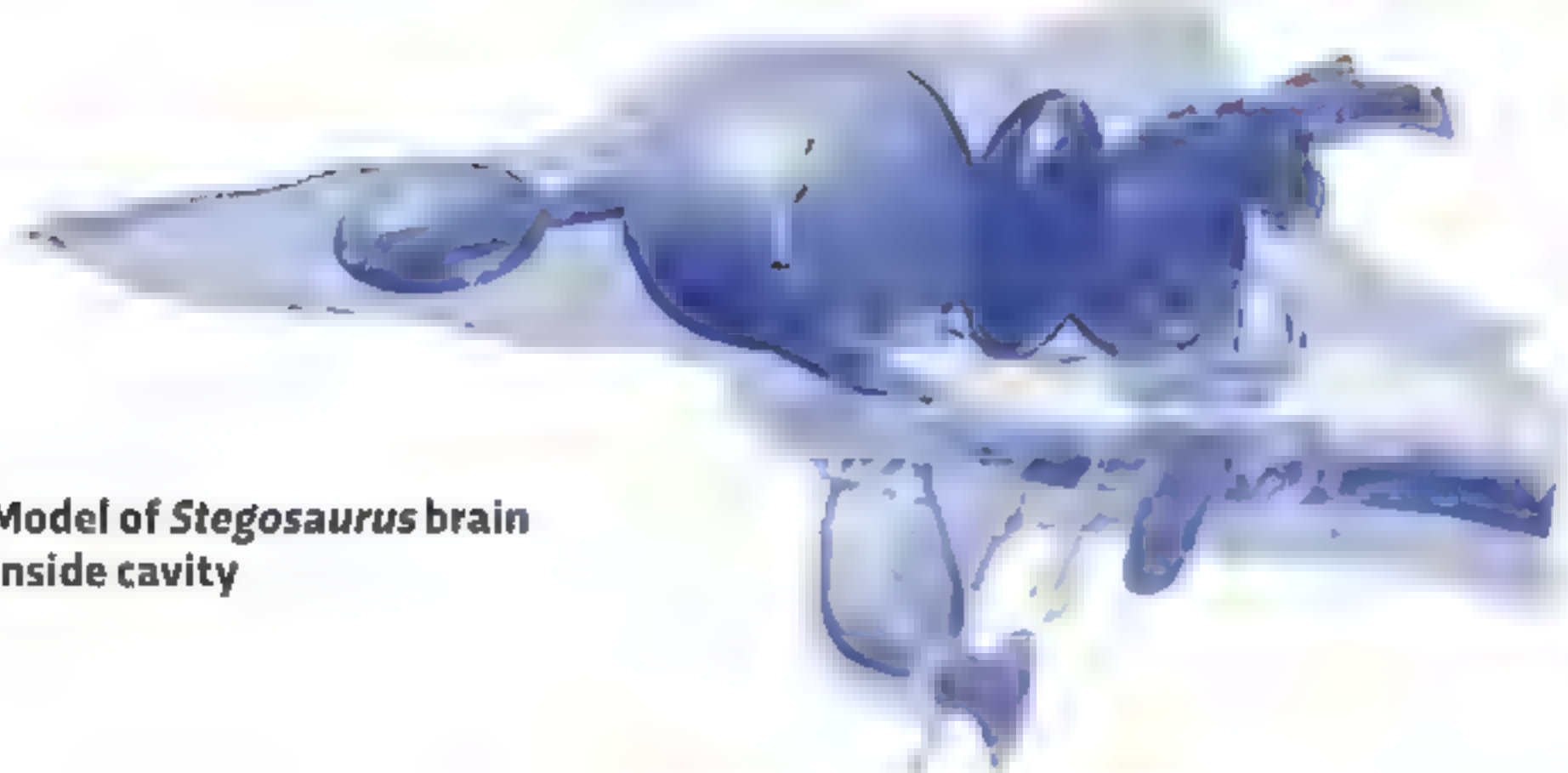
The *Stegosaurus* was historically accused of being stupid. However, recent research has proved that this wasn't the case – it had plenty of brain for its needs



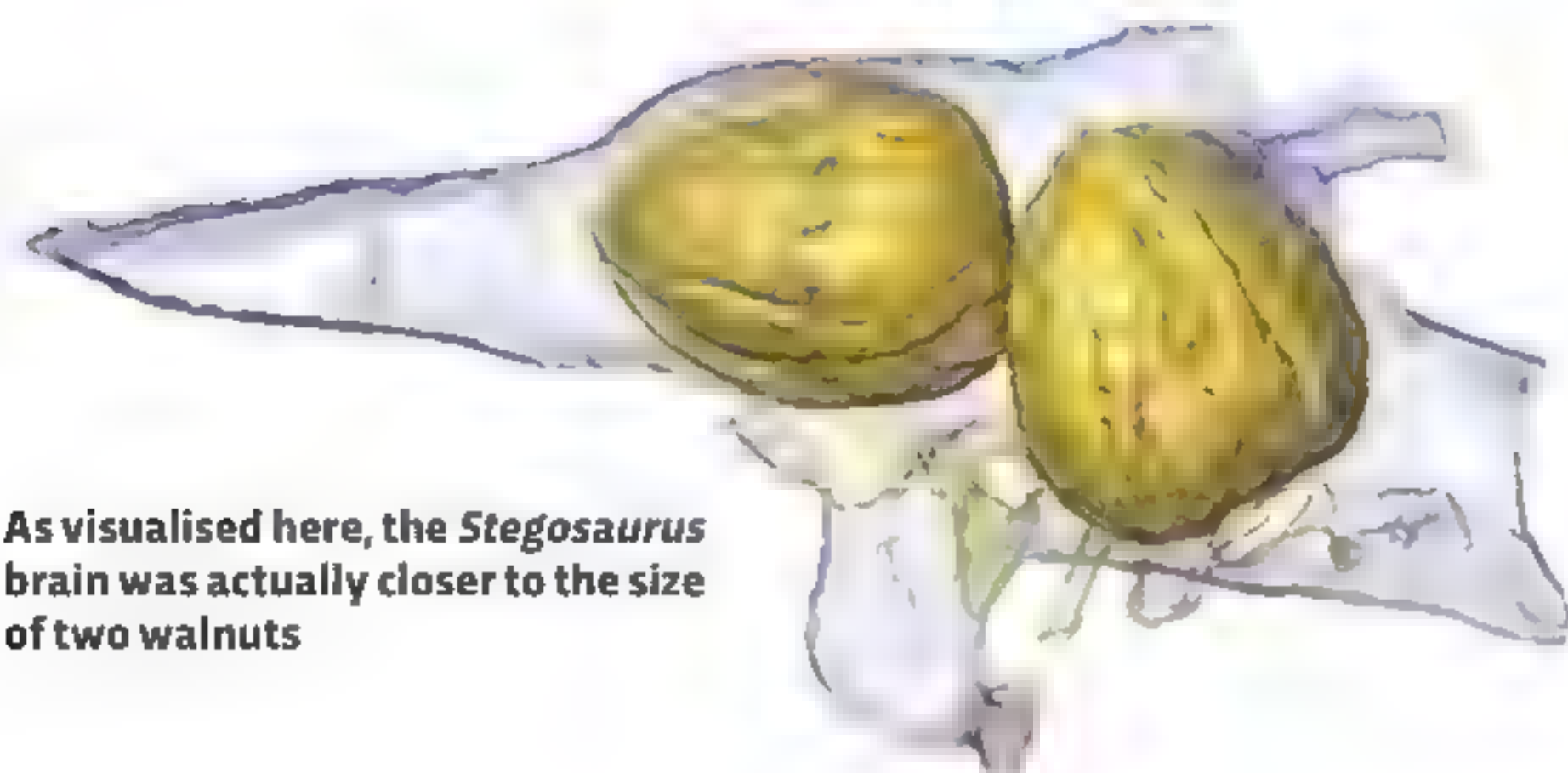
Location of brain cavity in *Stegosaurus* skull



Stegosaurus brain cavity



Model of *Stegosaurus* brain inside cavity



As visualised here, the *Stegosaurus* brain was actually closer to the size of two walnuts

'walnut-sized' brain exemplifying how dinosaurs were lethargic dullards that were poorly suited to their environments. As with so many cherished stories about dinosaurs, this turns out to be mostly wrong. Dr Ashley Morhardt, a palaeontologist at Washington University in St Louis, Missouri, scanned a *Stegosaurus* skull and found that the brain is indeed small for a dinosaur, but it was closer in size to two or three walnuts. No doubt, this was more than enough brainpower for *Stegosaurus* to survive in the rough-and-tumble world of the Jurassic. Even the dumbest dinosaurs were much smarter than popular culture gives them credit for.

Another group of herbivores modified the brain and inner ear to fit their lifestyles. Sauropods – the group of pot-bellied, long-necked behemoths that included *Diplodocus* and *Brontosaurus* – were the biggest animals to ever live on land. The earliest sauropods were dog-sized critters such as the Triassic's *Saturnalia*, which had a small brain with big flocculus lobes that permitted fine-tuned head, ●



● neck and eye movements. As sauropods got bigger and started walking on four legs, the flocculus got smaller, as did the semicircular canals of the ear, which help regulate balance. It seems as if sophisticated locomotion was becoming less important to these animals as they devoted more time and energy to eating the huge quantities of leaves and stems needed to power their ever-growing metabolism.

There's something else peculiar about the hugest sauropods: different species had inner ears oriented in different directions. It's widely known that in living animals the lateral semicircular canal of the ear is held in a horizontal plane when the animal employs a 'neutral' head posture. A study by University of Chicago palaeontologist Dr Paul Sereno found that some sauropods, such as the spatula-toothed *Camarasaurus* stuck their heads out nearly straight when in this neutral posture, but others like *Nigersaurus* pointed their heads downwards. This suggests that *Camarasaurus*-type sauropods lifted their necks high into the air, whereas *Nigersaurus* was more like a vacuum cleaner that sucked up plants near the ground. Sauropods were evidently changing their sensory systems to allow them to feed in different styles and on different types of plants, which is probably one reason why so many species were able to coexist in the same environments, as they weren't competing with each other. Sensory changes, therefore, were one of their keys to success.

WHO'RE YOU CALLING FEATHERBRAINED?

Meat-eating theropods, such as *T. rex* and *Velociraptor*, are celebrated for their sharp teeth and killer claws, but their arsenal of predatory weapons also included keen intelligence and senses. The smartest dinosaurs of all were small, feathered species closely related to birds, such as *Velociraptor*, *Troodon* and *Zanabazar*.

Dr Amy Balanoff of Johns Hopkins University has built her career studying the brains of dinosaurs, meticulously scanning fossil after fossil, including



ABOVE LEFT: By studying the brain and ears of *Nigersaurus*, scientists established that this sauropod fed on plants near the ground

ABOVE: In the Gobi Desert, Dr Mark Norell has excavated a lot of Cretaceous-aged skulls, many of which are from fast, intelligent dinosaurs that have brains extremely similar to ancient birds

many stellar Cretaceous-aged skulls (around 75-80 million years old) that Dr Mark Norell, a palaeontologist from the American Museum of Natural History, excavated from the Gobi Desert. These feisty, fast-running predators had, proportionally, the largest brains, relative to body size, of any dinosaurs. This is largely due to their enlarged cerebrums and it means that they were probably among the most intelligent of all dinosaurs. Not only that, but their brains are essentially indistinguishable in size and shape from the brains of the oldest birds, which may indicate that some of these *Velociraptor*-grade theropods were capable of flight. Work by University of Calgary palaeontologist Dr Darla Zelenitsky has also shown that the 'raptor' dinosaurs had proportionally huge olfactory bulbs relative to most other theropods, suggesting they used a sharp sense of

"Tyrannosaurus rex's brainpower and sensory acumen ensured that it was the biggest, baddest predator that ever lived"

DINOSAURS AMONG US?

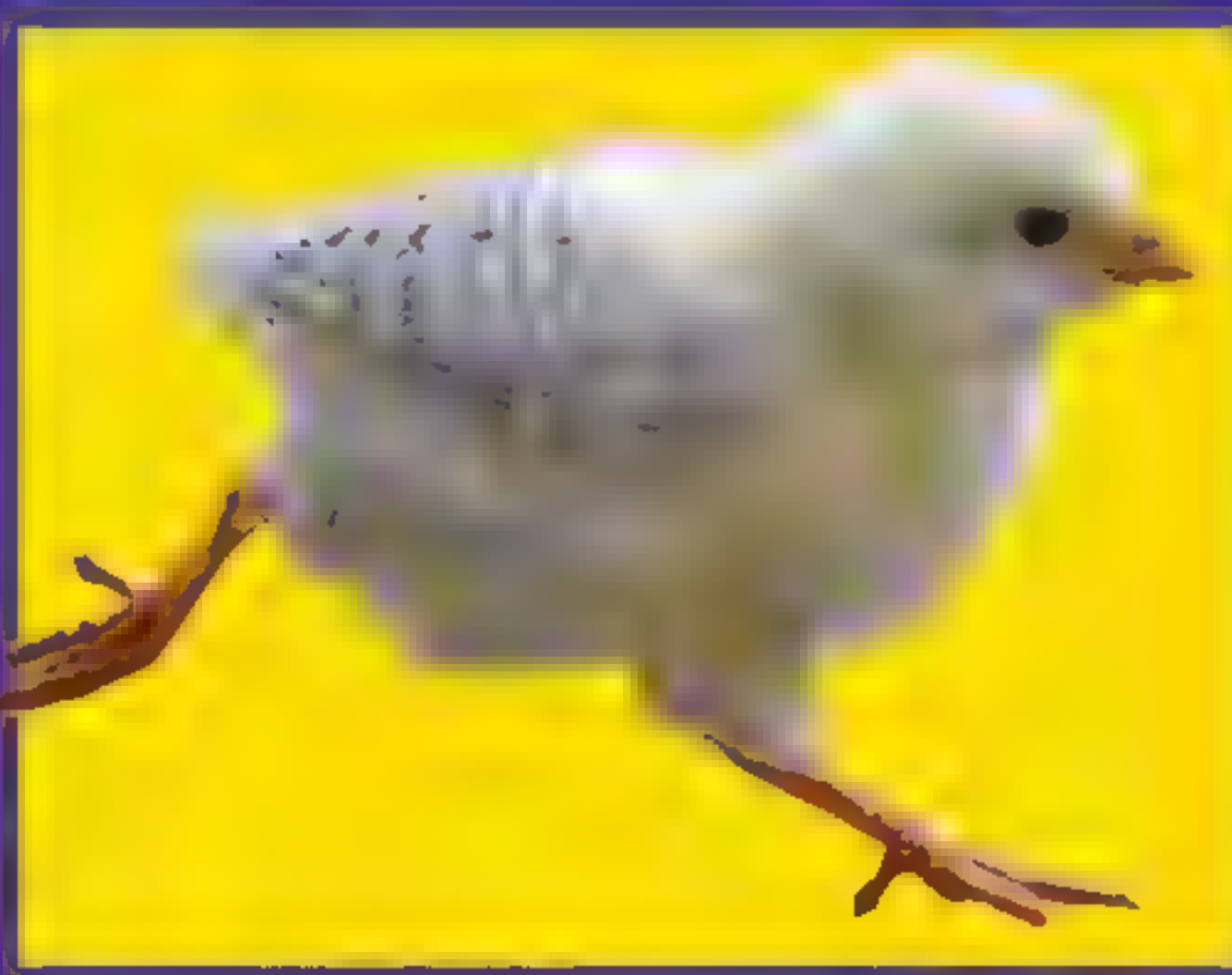
WORDS: DR DARREN NAISH

There is scientific value in using modern animals as analogues for those that went extinct millions of years ago. But it has to be done carefully, and any inferences made about dinosaurs' lives and behaviours based on those of living species come with a plenty of caveats. Palaeontologists limit the species they're analysing using a technique called 'phylogenetic bracketing', where they look at the evolutionary tree to which the extinct animal belongs and the existing animals that are closely related to it. The result is that if we wish to know about any aspect of dinosaur biology or anatomy not preserved in fossils, we can look to its closest living relatives for clues.



Zip it

It's impossible to know what sounds dinosaurs made as their noise-making organs have not been preserved. But both crocodilians and birds (which share a common ancestor with dinosaurs) possess a larynx. Crocodiles and large birds, such as emus, use this organ to make deep, rumbling sounds, so it's possible that dinosaurs did too. But rather than open their mouths or beaks to let out these noises, they use their puffed-out necks or chests as reverberating chambers. So even if *T. rex* did roar, chances are it didn't do it with a wide-open mouth.



Chicken dance

Modern birds are different from theropods like *T. rex* and *Velociraptor* as they have substantially shorter tails, wider hips and rely on their knees more than their hips to move their legs. In an effort to compensate for these differences and better understand the locomotion in ancient theropods, scientists attached long, tail-like prostheses to the rear ends of chickens. The birds learnt to walk with more of a 'dinosaur gait', proving that birds still have this ability even if aspects of their proportions undergo change.



Claw-some

Dromaeosaurids, the theropod family that includes *Velociraptor*, often had large, curved and pointed claws on their feet that were held up off the ground. It was thought that the animal would stand on one leg and kick at a prey animal to disembowel it using its claw. But this technique is not used by any modern predator. By examining the hunting behaviour of owls, hawks and eagles, which have similarly clawed feet, researchers have come to the conclusion that these dinosaurs used their claws to pin down prey while attacking it with their mouths.

smell to seek out their prey. Whether they were capable of the kind of cunning depicted in *Jurassic Park* is a matter of speculation, however!

As fearsome as a pack of *Velociraptors* would have been, no theropod eclipses the King of Dinosaurs: *T. rex*. Over a century ago, Osborn's sawed-up skull hinted that *T. rex* had a fairly large brain and more recent CT work by Dr Larry Witmer of Ohio University confirms it. In fact, not only was *T. rex* roughly as intelligent as a chimp, but it had enormous olfactory bulbs that imparted a strong sense of smell, elongate and looping inner ear canals that coordinated rapid eye movements and quick reflexes, and an elongate cochlea that could hear low-frequency sounds. If a 13-metre-long, 7-tonne, bone-crunching predator wasn't scary enough, its brainpower and sensory acumen ensured that *T. rex* was the biggest, baddest predator that ever lived.

This raises a question: how did *T. rex* evolve these features? The boxed-up skull that Averianov gave me in Berlin provides the answer. When I brought

the skull to Edinburgh, I handed it over to Dr Ian Butler, my geochemist colleague who hand-built his own CT scanner, and my student Amy Muir, a maestro at reading CT scans. Our visualisation of the brain showed that the skull – which we later named as a new species, *Timurlengia euotica* – had the characteristic elongate and peaked brain of *T. rex*, with a long cochlea. But *T. euotica* was much smaller, only about the size of a horse, and lived about 25 million years before *T. rex*. Thus, the ancestors of *T. rex* evolved big brains and keen senses before they developed huge body size. So tyrannosaurs got smart before they got big – and getting smart was probably what allowed them to rise to the top of the food chain, grow to monstrous sizes and become the ultimate dinosaur success story. 🦖

Dr Stephen Brusatte is a palaeontologist at the University of Edinburgh and is the author of many books on dinosaurs. His newest book, *The Rise And Fall Of The Dinosaurs*, was published in May 2018 (£20, Macmillan)

JURASSIC PARK

This summer marks the 25th anniversary of Jurassic Park. When the film was released in 1993, it presented a new image of dinosaurs far different from the plodding dullards of old films and textbooks. Much of what we've learned over the past quarter of a century corroborates this image: dinosaurs were active, energetic and intelligent creatures that were closely related to birds. But palaeontologists have learned a lot about dinosaurs over the last few decades, as a result of hundreds of new fossil species being discovered and the introduction of cutting-edge technologies like CT scanners and computer animation software. Here are five things that we now know were incorrect about the dinosaurs in Jurassic Park...

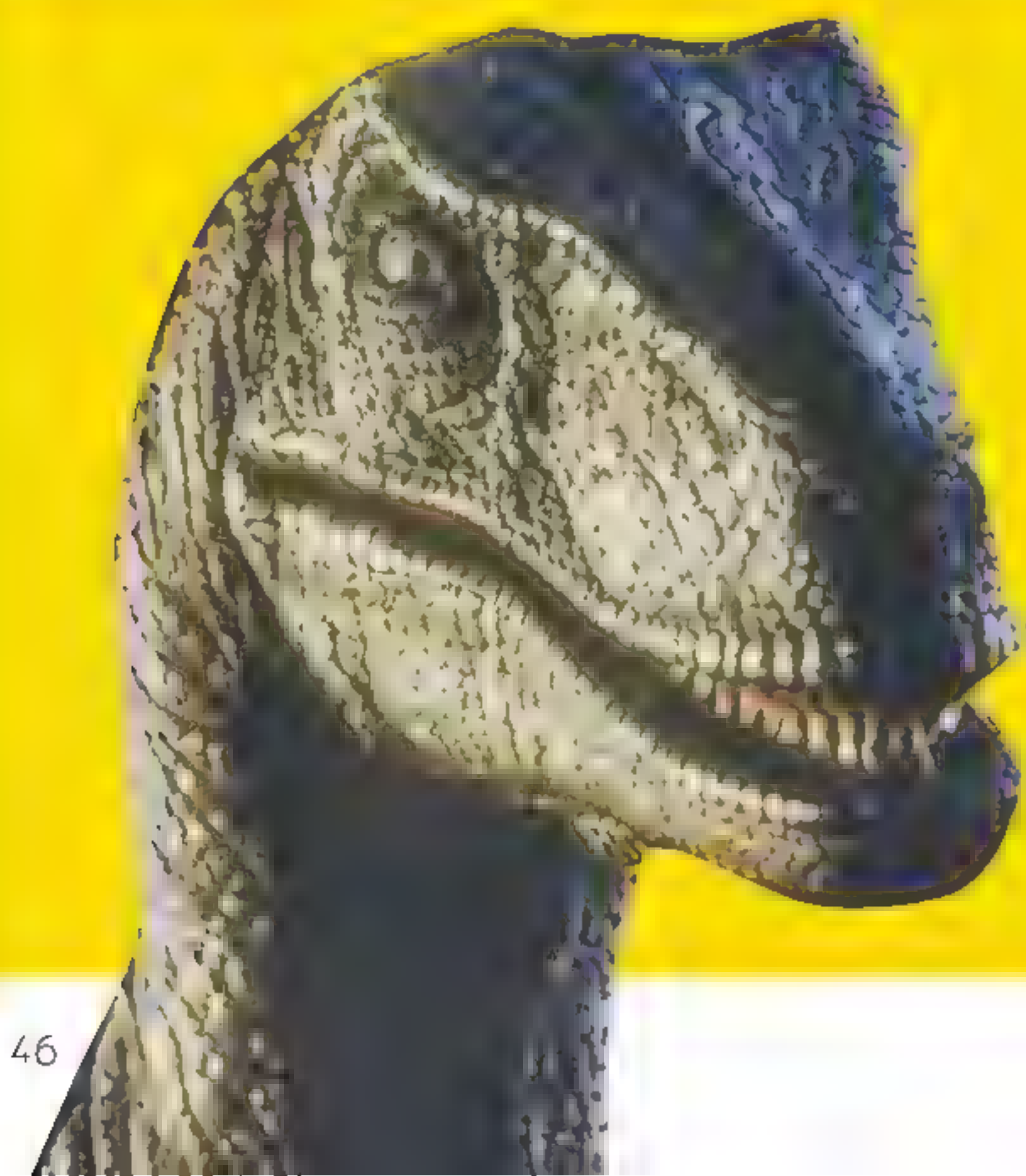
1) LACK OF FEATHERS

The scaly *Jurassic Park* dinosaurs look quite a bit like oversized lizards. This is how dinosaurs used to be depicted in children's books and museum exhibits, and it was still the current thinking in 1993. But then, in 1996, everything changed. A farmer in Liaoning, China, discovered the skeleton of a dinosaur covered in feathers. Hundreds more soon followed. These feathered dinosaurs showed once and for all that birds evolved from dinosaurs. It also proved that many dinosaurs had feathers, including small carnivores like *Velociraptor*, bigger meat-eaters like *T. rex*, and even some plant-eating dinosaurs. A lot of palaeontologists now think that all dinosaurs had some type of feathers. Small, wispy 'protofeathers' (hair-like precursors of modern bird feathers) were added to some of the dinosaurs in some of the later *Jurassic Park* films, but in the most recent *Jurassic World* the dinosaurs were scaly once again.



2) DULL SKINS

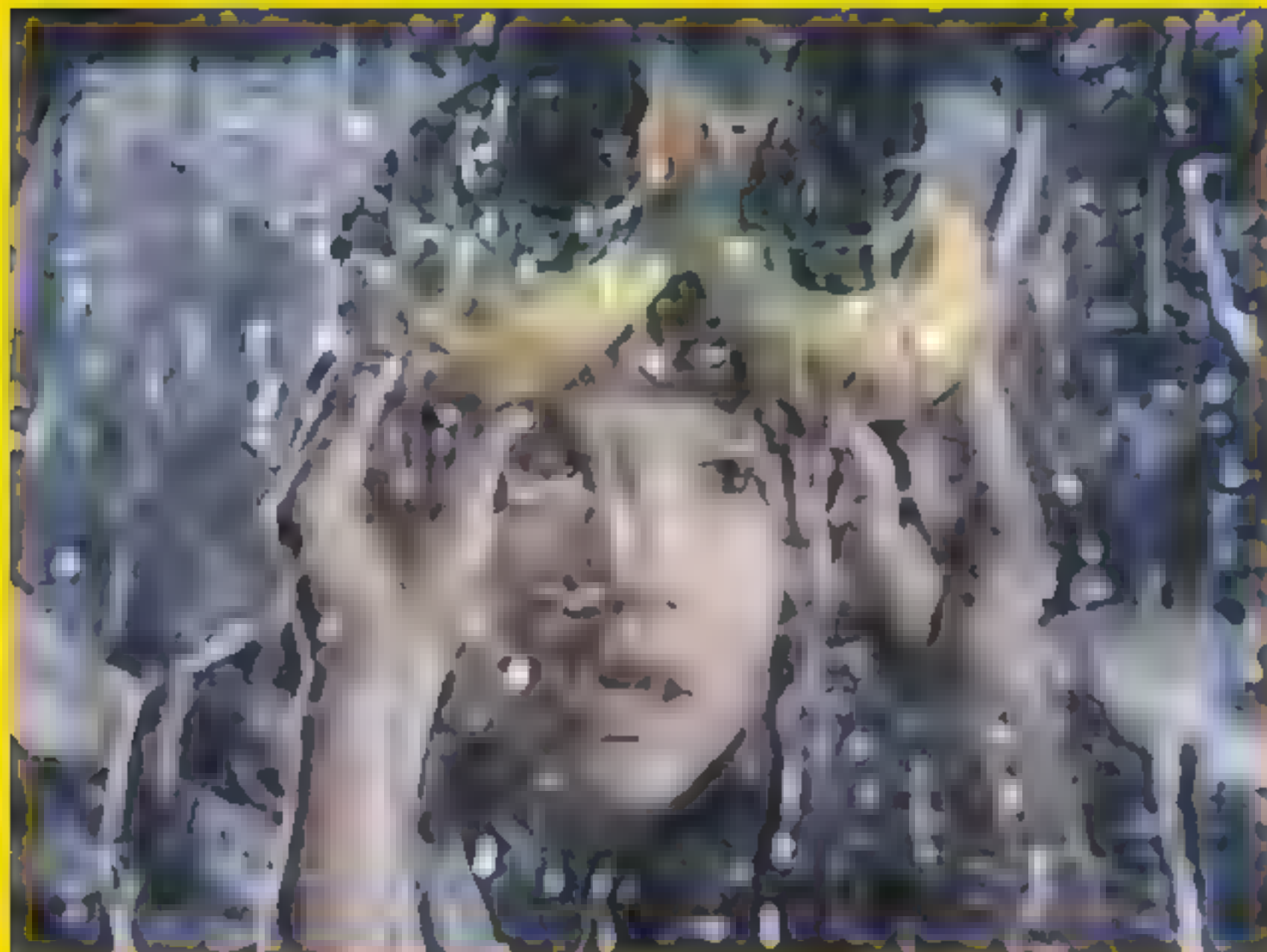
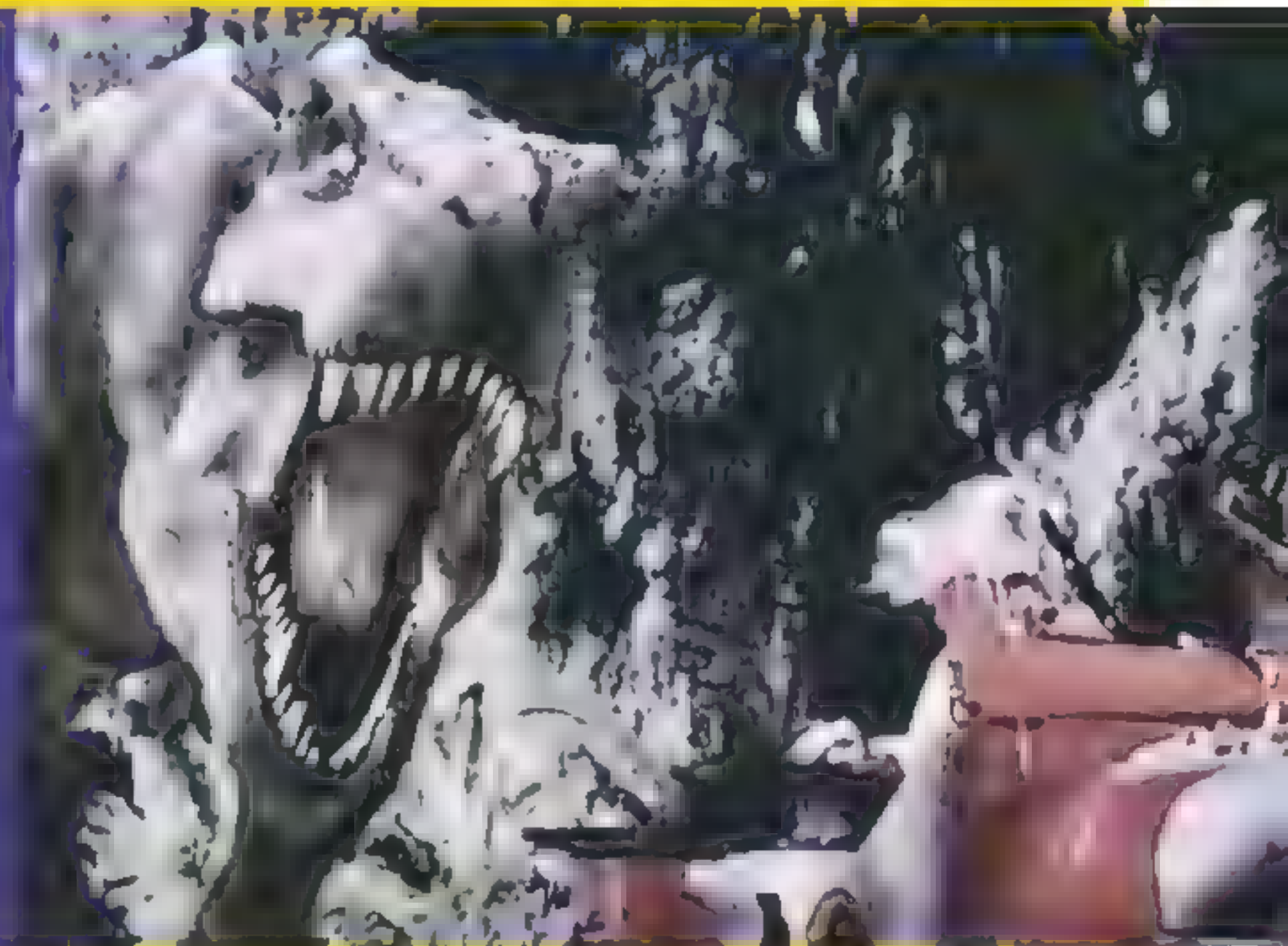
Not only are the *Jurassic Park* dinosaurs scaly, but they are mostly drab in colour, with green, brown or earth-toned skin that also appears reptilian in style. Not all dinosaurs would have looked like this, however. In the late 2000s, a graduate student called Jakob Vinther figured out how to tell the colour of dinosaurs. He found that if you put well-preserved feathers or skin under a scanning electron microscope, you can see pigment-bearing vessels called melanosomes. We know from modern animals that different-shaped melanosomes correspond to different colours: sausage-shaped ones make black, meatball-shaped ones a rusty red, and so on. Through this technique, we now know that dinosaurs came in all sorts of fantastic colours, just like today's birds. Some were black or white, others brown or ginger, some were multicoloured or iridescent, and one small carnivore called *Sinosauropteryx* even had a ringed tail of red and white bands.



25 YEARS ON

3) SPEEDY *T. REX*

A famous scene in *Jurassic Park* shows a bloodthirsty *T. rex* chasing down a jeep moving at highway speeds. This was a reasonable assumption to make in 1993, as the long and muscular legs of *T. rex* looked like they were capable of great bursts of speed. Computer modelling studies, however, have revealed something quite different. Work by Dr John Hutchinson in the early 2000s found that *T. rex* would have needed laughably huge leg muscles – making up an absurdly impractical 86 per cent of total body mass – to move at more than 32km/h (20mph). And then, even if this were somehow possible, the massive seven-tonne bulk of *T. rex* would have made it liable to tip over when running, like a truck taking a corner too quickly. The modern image of *T. rex* is an animal that probably maxed out at about 16-24km/h (10-15mph).



4) YOU'RE SAFE IF YOU'RE STILL

There's something else that *Jurassic Park* got wrong about *T. rex*. Recall the scene where the frightened youngster is told to stand still, because the *T. rex* is incapable of sensing prey that doesn't move? New research shows that this advice would have proven deadly. CT scans reveal that *T. rex* had a large brain, with huge olfactory lobes that powered a highly sensitive nose, and an inner ear with a long cochlea that could hear a wide range of sounds. Furthermore, the eyes of *T. rex* faced partially forward, permitting binocular vision with keen depth perception. Add this all together and you get a smart animal with sharp senses that probably would have seen, smelled and heard the little boy. These superpowers were as much of a part of *T. rex*'s predatory arsenal as its claws and teeth.

5) CLONES FROM FOSSILS

The science of dinosaurs has progressed at an exponential pace over the last few decades, but there are still many things we don't know. One of the great hopes of the *Jurassic Park* era – and the premise of the entire movie franchise – was that dinosaurs could one day be cloned from fossilised remnants of their DNA. Many palaeontologists have been looking, but as yet, not one fragment of the dinosaur genome has been recovered. And maybe it never will: DNA degrades quickly once an animal dies, so preserving even small amounts for millions of years may be purely in the realm of sci-fi. Still, palaeontologist Dr Mary Schweitzer and her team have defied the odds and identified bits of dinosaur soft tissue like proteins and blood vessels, so maybe DNA is next...



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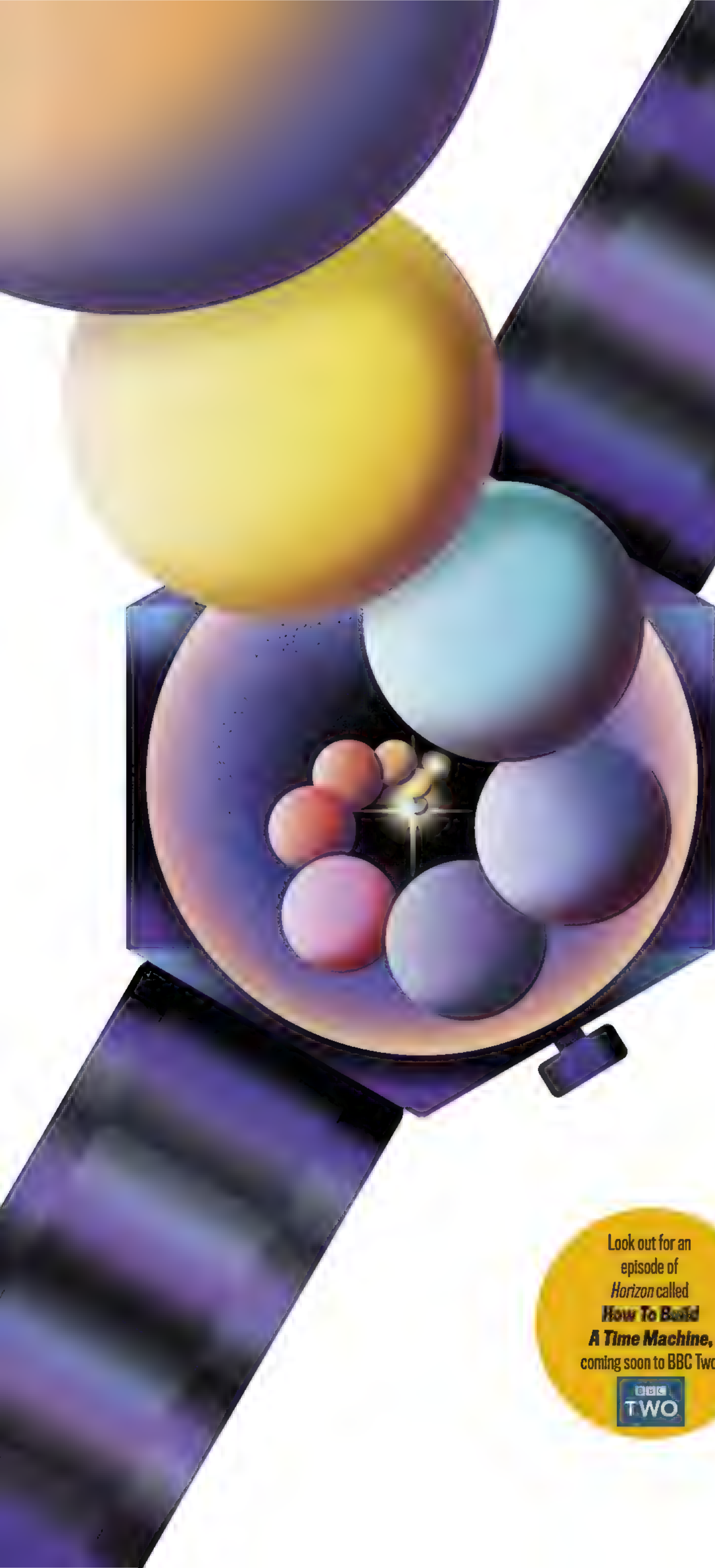


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TIME TRAVEL: A USER'S GUIDE

*In 1915 in Berlin, at the height of WWI, Albert Einstein presented a revolutionary new theory of gravity – the General Theory of Relativity. It has since become one of the most successful theories ever, passing every observational test thrown at it and predicating cosmological phenomena such as the Big Bang, black holes and gravitational waves. But the theory has also given scientists sleepless nights because it makes one thing pretty much unavoidable: **time machines...***



...It comes down to the fact that, in Einstein's theory, time is not absolute, ticked off by a universal clock with which everyone agrees, but instead is relative. "I can't talk to you in terms of time – your time and my time are different," wrote the English novelist Graham Greene.

According to Einstein, the rate at which time flows for someone depends on how fast they're moving relative to you and the strength of the gravity they're experiencing. If you can find a way to jump from a region where time flows at one rate to a region where it flows at slower rate, you can go back in time – you'll have made a time machine.

The recognition that time is not what you think it is goes back to the Special Theory of Relativity that Einstein published in 1905, and it all hinges on the unique properties of the speed of light. Einstein realised that nothing can travel faster than light – it is the cosmic speed limit of our Universe. This makes light uncatchable by anything. He also discovered that intervals of space and time stretch like elastic as massive objects move through them. By a cosmic conspiracy this means that everything measures exactly the same speed for a light beam, no matter how fast that thing is travelling or in which direction.

To be a little more precise, moving clocks run slow. So, if someone flies past you – and it has to be at a speed approaching 300,000 kilometres per second – then their clock will run slow compared to yours. If they could ever reach the speed of light – which is impossible for a material body, though possible for a massless entity such as a particle of light (a photon) – time would come to a complete standstill. ►

Look out for an episode of *Horizon* called **How To Build A Time Machine**, coming soon to BBC Two.



ILLUSTRATIONS MERIN HOS

“This violation of causality gives scientists sleepless nights since it’s synonymous with time travel”

OPTION 1: Travel faster than light

What if you could travel faster than light? If you could, then you would arrive at your destination before you set off. This so-called ‘violation of causality’ gives scientists sleepless nights since it’s synonymous with time travel. If you travelled faster than light from Earth to the nearest star system, Alpha Centauri, then a light beam leaving at the same time would still be on its way by the time you had arrived. This makes it possible for you to look back at Earth and see your spacecraft blasting off.

But how would you ever be able to travel *faster* than light if nothing material can even achieve the speed of light? Physicists have postulated the existence of hypothetical particles called tachyons. Tachyons are born moving faster than light, just as photons (particles of light) are born travelling at the speed of light. If we could convert the atoms of our bodies into tachyons, fire them across space, then change them back into atoms, we could travel faster than light. And some observers would see us going backwards in time.

But there’s a catch. In 1974, US physicist Richard Gott of Princeton University discovered that a tachyon radiates a cone of gravitational waves (ripples in space-time) that trails behind it, much like the way an aeroplane creates a sonic boom when exceeding the speed of sound. Thanks to the tachyon’s unusual properties, this cone would cause the particle to lose energy and speed up – the opposite of what you might expect – before finally colliding with an equally fast-moving anti-tachyon and annihilating. Although the collision would occur at infinite speed, Gott’s solutions suggest that most of a tachyon’s life would be spent moving at barely above the speed of light. However, this would make any time travel effect exceedingly small.

Time travel is possible, but you have to become a hypothetical particle called a tachyon. Probably not likely.

TIME TRAVEL: A PRIMER

Black hole

A region of space-time with such intense gravity that nothing can escape

Cosmic strings

Hypothetical thin ‘tracks’ of space-time left over from the universe’s formation

Photon

A particle of light

Space-time

The fabric of three-dimensional space (length, width, height) with time to make four-dimensional space-time. It is warped in the presence of matter such as stars and planets

Tachyon

A hypothetical particle that moves faster than the speed of light

General Relativity

This 1915 theory built on Special Relativity by adding gravitational effects and proposing that space-time is curved

Special Relativity

Einstein’s first theory of the structure of space-time, introduced in 1905. It’s based on the postulates that the laws of physics are the same for all observers in uniform motion relative to one another, and that the speed of light in a vacuum is the same for all observers

Wormhole

Theoretical tunnel through space-time that could provide shortcuts to another region of the universe



OPTION 2: Spin the Universe

In 1949, Kurt Gödel, Einstein's friend and Princeton colleague, figured out a solution that made it possible for the Universe to contain ready-made time machines. All it requires is that the Universe is rotating. This Gödel Universe contains closed loops that literally act like time machines. Travel around one and you would arrive at yesterday. Go around again and you'd get to the day before that.

The path of light rays in a Gödel Universe is bent into a banana shape by cosmic rotation. This means that it's always possible to beat a light beam – that is, to travel faster than light – by travelling in a straight line from one tip of the banana to the other.

Scientists, including Einstein, were spared sleepless nights because nature doesn't appear to have created a rotating Gödel Universe. Instead, as American astronomer Edwin Hubble discovered in the 1920s, we live in expanding Universe whose galaxies are flying apart like pieces of cosmic shrapnel in the aftermath of a titanic explosion: the Big Bang.

A spinning Universe would create ready-made time machines. Sadly, our Universe doesn't spin. ➤

OPTION 3: Split the Universe

If all these time machines seem contrived and wildly impractical, well, they are. But that's not the point. The point is that time travel is possible in principle. And that permits nightmare paradoxes to raise their heads. For instance, you could use a time machine to go back in time to murder your grandfather before your mother was born. The question would then be: how could you have murdered your grandfather if you had never been born? To avoid the grandfather paradox, the late Stephen Hawking proposed the 'chronology protection conjecture'. This is just a fancy way of saying: time travel is impossible. Hawking was convinced that some undiscovered law of physics must intervene to prevent it ever happening.

But there's another way out of the grandfather paradox. Quantum theory is our best description of the microscopic world of atoms and their constituents. But it implies that fundamental particles can do many things at once, the equivalent of you doing shopping and mowing the lawn at the same time. According to the many worlds interpretation of quantum theory, every time a quantum event occurs – for instance, a photon is emitted by an atom or not emitted by an atom – both things happen but in parallel realities. The Universe is constantly splitting into versions that play out all possible histories and there are infinite parallel realities stacked like the pages of a neverending book. In the many worlds scenario, if you go back in time and kill your grandfather, you kill a parallel grandfather in a parallel universe, not your one. Hey presto, time travel without the paradoxes.

If the Universe contains parallel realities, then tricky time travel paradoxes are avoided.



OPTION 4: Jump through cosmic strings

It's possible to build a time machine using cosmic strings. These one-dimensional faults in space-time preserve the high-energy conditions of the ultra-early Universe. Cosmic strings are analogous to the cracks that form when water freezes to make ice and they crop up in about half the theories proposed to unify nature's fundamental forces. They have no ends and, in an infinite Universe, are either infinite in extent or exist in closed loops.

Cosmic strings are under enormous tension, which causes them to straighten out with time and lash about at speeds typically greater than half of the speed of light. In General Relativity, such tension gives rise to repulsive gravity. So, despite the fact that strings have enormous masses – about 10 million billion tonnes per centimetre – their gravity is cancelled out and doesn't affect nearby objects.

“A cosmic string represents a tiny chink in the armour of space-time”

The hint that a string might be used for time travel comes from what it does to space-time. Imagine the string coming up through this page and a circular disc of space-time surrounding it in the plane of this page. This is normal space-time. But a string does something weird to space-time: it cuts out a chunk like a pizza slice. On either side of the missing slice, the space-time joins up. So, the space-time around the string, rather than being flat, is a shallow cone. Suddenly it's possible to see how to go faster than a light beam. Travelling around the string is a shortcut through space-time because it's possible to complete a circle without having to travel 360°. It should be pointed out that the pizza slice that's cut out of space-time is teeny, about a thousandth of a degree. So, a cosmic string represents only a tiny chink in the armour of space-time and it requires considerable ingenuity to exploit it for time travel.

However, in 1991, physicist Richard Gott imagined a peculiar scenario in which two infinitely long cosmic strings are passing each other in opposite directions at 99.999999996 per cent of the speed of light, which would warp space-time even further. According to Gott, the space-time of this cosmic string solution would be sufficiently twisted that it would be possible to travel anticlockwise around the two moving cosmic strings, always towards the future and still arrive home when you started. He likens it to an Escher drawing in which monks travelling clockwise on a staircase are always climbing higher but, after circling around a courtyard, find themselves back where they started.


Cosmic strings warp space-time, so time travel could be possible if we zoom around them.

OPTION 5: Take a wormhole shortcut

According to General Relativity, time flows at different rates in different gravity. So to create a time machine, we just need to connect two such regions and travel between them.

Imagine one place on Earth where time passes at the normal rate and another place near a black hole, where time flows more slowly thanks to the intense gravity. If two identical clocks begin ticking on Monday – one on Earth and one at the black hole – by the time it's Friday on Earth, it would only be Wednesday at the black hole. So, if you could travel instantaneously from Earth to the black hole, you could go from Friday back to Wednesday. Theoretical physicists Michael Morris and Kip Thorne proposed such a method using a wormhole.

A wormhole is a shortcut through space-time, predicted by Einstein. Imagine two points, A and B, on a piece of paper. If the paper is folded in two, A and B are now much closer. If they could be connected somehow you could travel between them more quickly than if you had to go across the paper. This is a shortcut analogous to a wormhole. If the Earth and the black hole are connected by such a wormhole, we have a time machine. The problem with wormholes is they snap shut in the blink of an eye and would have to be propped open by something with repulsive gravity for us to travel through them. Actually, most of the stuff in the Universe – dark energy – does have such repulsive gravity. The problem is it's too weak to keep a wormhole open. Also, in order to prop open a wormhole big enough for a person to crawl through, we'd require energy equivalent to that radiated by many of the stars in our Galaxy over their entire lives.

Wormholes offer a way to travel through space to a region where time flows differently. The problem is keeping the wormhole open. 

Marcus Chown is the author of *The Ascent Of Gravity* (£16.99, Weidenfeld & Nicolson), which was *The Sunday Times* science book of the year

DEEP THOUGHT

These remora use modified dorsal fins to attach harmlessly to larger animals, enjoying the protection offered by the host

Think of intelligence in the animal world and you rarely think of fish. But there's growing evidence to show that the various species living in the planet's waters have greater intellects than we've given them credit for

WORDS: DR HELEN SCALES

any people don't think of fish as being intelligent. Fish brains are too small and they're too distantly related to humans to be clever; they lack feelings; they can't feel pain – at least that's how they've been typecast. Their simple-minded reputation means that people still tend to treat fish differently from other animals, with far less concern for their welfare (just imagine if we slaughtered cows by drowning them in the sea).

In the past many scientists overlooked fish intelligence and didn't bother testing for it. Those that did often used experiments that weren't relevant for these animals, with senses so different from our own. But the science of fish cognition is catching up, and new studies are showing that fish are much smarter than previously thought. Signs of higher intelligence among fish are not only forcing a rethink of their lives and the way we treat them, but also how brains and animal intelligence evolved.



Sharks are not just predators, they are also intelligent. They can learn from experience and use tools. They can also communicate with each other. This is a new discovery. It shows that sharks are much smarter than we thought. They can learn from experience and use tools. They can also communicate with each other. This is a new discovery. It shows that sharks are much smarter than we thought.



LEFT: Marine biologist Eugenie Clark, seen here examining deep-sea sharks, was the first to show that sharks can be trained using food

BELOW LEFT: Studies on manta rays suggest they may be self-aware, yet it's likely that the fishy world contains more examples of this

RIGHT: In this colour scan of a zebrafish, large eye can clearly be seen in blue

THEY CAN LEARN

In the 1950s, US biologist Eugenie Clark first showed that sharks can be trained using food rewards, just like lots of other animals. More recently, researchers in the Bahamas taught captive lemon sharks to press a target with their snout in return for food (image of lemon shark on previous page). When sharks were kept with others that already knew what to do, they learned the task faster than when they were left to figure things out for themselves. This kind of social learning is another important aspect of animal intelligence. Other studies have shown that young lemon sharks prefer to hang out in gangs with other sharks they already know. It's not yet known if they simply distinguish between familiar versus unfamiliar sharks, or if they recognise individuals.

RIGHT: Groupers and eels will buddy up to increase the efficiency of hunting trips



THEY'RE SELF-AWARE

When scientists from the University of South Florida lowered a giant mirror into an aquarium, two manta rays circled around it, gazing at their reflections. Did the mantas realise they were looking at themselves? Were they self-aware? The scientists involved think so (although not everyone agrees). They argue that when the mantas blew bubbles at their reflections, by dislodging air caught in their gills, this could have been a process known as contingency checking, just like you might wave your hand to check it's your reflection in a distant window.

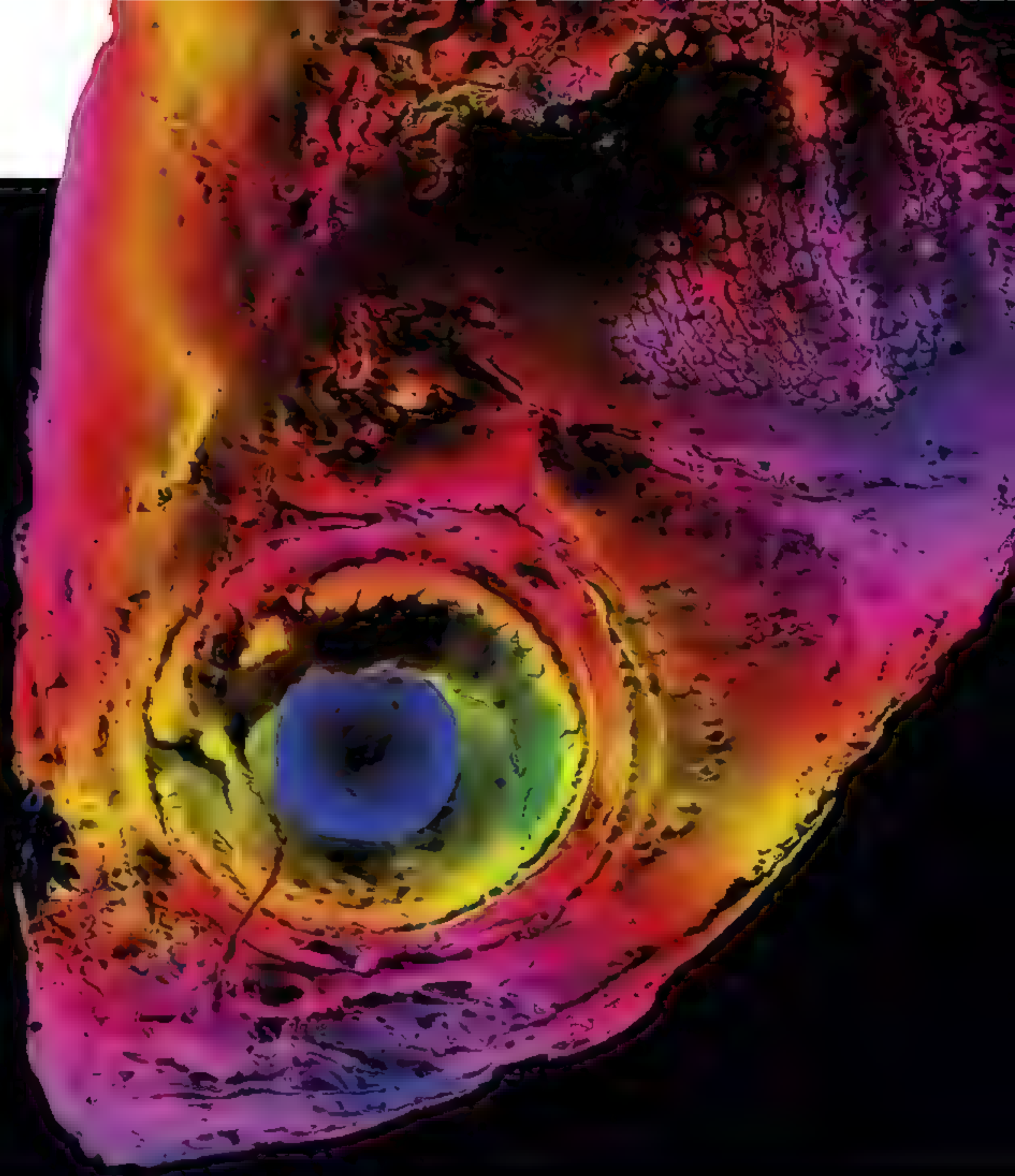
Another self-awareness test involves painting a dot on an animal's body somewhere they can only see in a mirror. A human toddler, adult chimpanzee and even some magpies will reach for and touch the unexpected dot. Of course, manta rays don't have hands or beaks, so there's no easy way of applying this test.

If mantas are eventually added to the small list of self-aware animals, which so far includes mainly mammals and a few birds, it will show that this trait probably evolved many times in the animal kingdom and could perhaps be more widespread than previously thought.

THEY FEEL

It's hard to tell if a fish is suffering. They make no sounds and have no facial expressions. But scientists have begun to work out other ways of gauging their mental state. Zebrafish, the lab rats of the fish world, have been shown to suffer from emotional stress. When trapped in a small net, a zebrafish's body temperature rises by several degrees. Known as emotional fever, this involves the body responding to stress in the same way it does following infection by a pathogen. It was previously thought that only humans suffered from stress like this.

The finding adds to mounting evidence that fish detect and feel pain, even though they lack a neocortex, which is the mammalian brain region responsible for pain perception. Following findings like these, standards for the ethical treatment of fish are gradually catching up to those for other animals. In Britain it's illegal to mistreat pet fish (recently a man was convicted of cruelty to animals when he allegedly swallowed a live goldfish) and in Germany recreational fishermen must keep, humanely kill and eat any fish they catch, without releasing them again, otherwise their sport is deemed to cause unnecessary suffering.

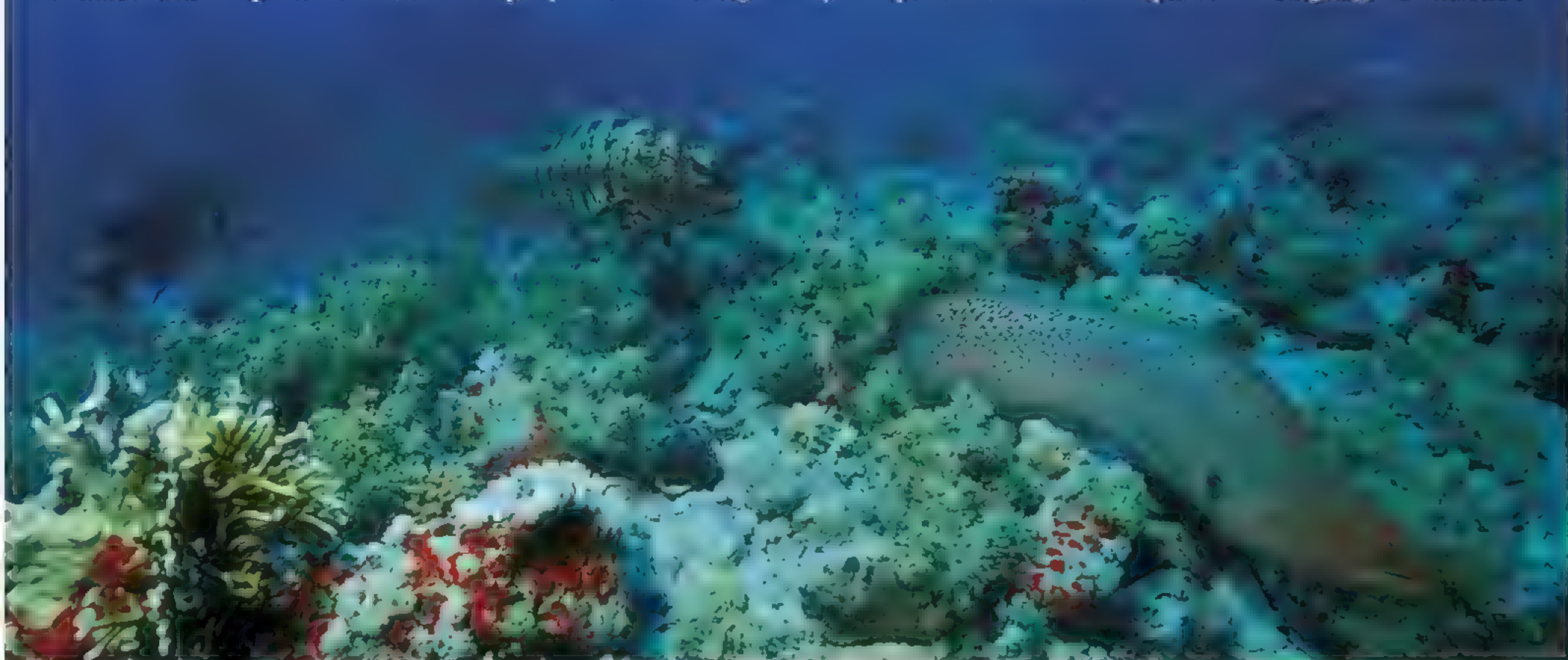


THEY POINT

Several years ago, scientists diving on the Great Barrier Reef spotted groupers behaving very strangely – they were doing headstands and shimmying their bodies. A team of diving scientists patiently watched many groupers doing this before finally working out what was going on.

When a grouper chases a smaller fish into the reef, usually it's too big to follow. So the grouper waits for another hunter to pass by, often a moray eel, then does a headstand to point to where the prey fish is hiding.

Many times, scientists saw eels responding to a grouper's gestures by sliding into the reef and either catching the prey or scaring it out of the reef and into the grouper's waiting jaws. A grouper and an eel will often set off on a hunting spree together across the reef. This is the first known case of fish forming interspecies hunting partnerships and pointing to each other. Using gestures like this is uncommon in the animal kingdom, and it's thought to be an important prerequisite for the development of language in humans.



5 GOLDFISH MYTHS BUSTED

That denizen of bowls throughout the country is deserving of so much more...



1: IT'S FINE TO KEEP GOLDFISH IN SMALL BOWLS

Nope. While goldfish can survive in cramped conditions, it's not good for them. To live to their full lifespan and size (they can reach 45cm), they need properly aerated, treated and filtered water.



2: EACH VARIETY OF GOLDFISH IS A DIFFERENT SPECIES

Wrong again. All goldfish are the same species, *Carassius auratus*, a type of carp originally from East Asia that's been selectively bred for hundreds of years.



3: YOU CAN'T TRAIN A GOLDFISH TO DO TRICKS

Yes you can! Like training a dog with food rewards, you can teach goldfish to swim through hoops, slalom between posts and even push a mini football into a net.



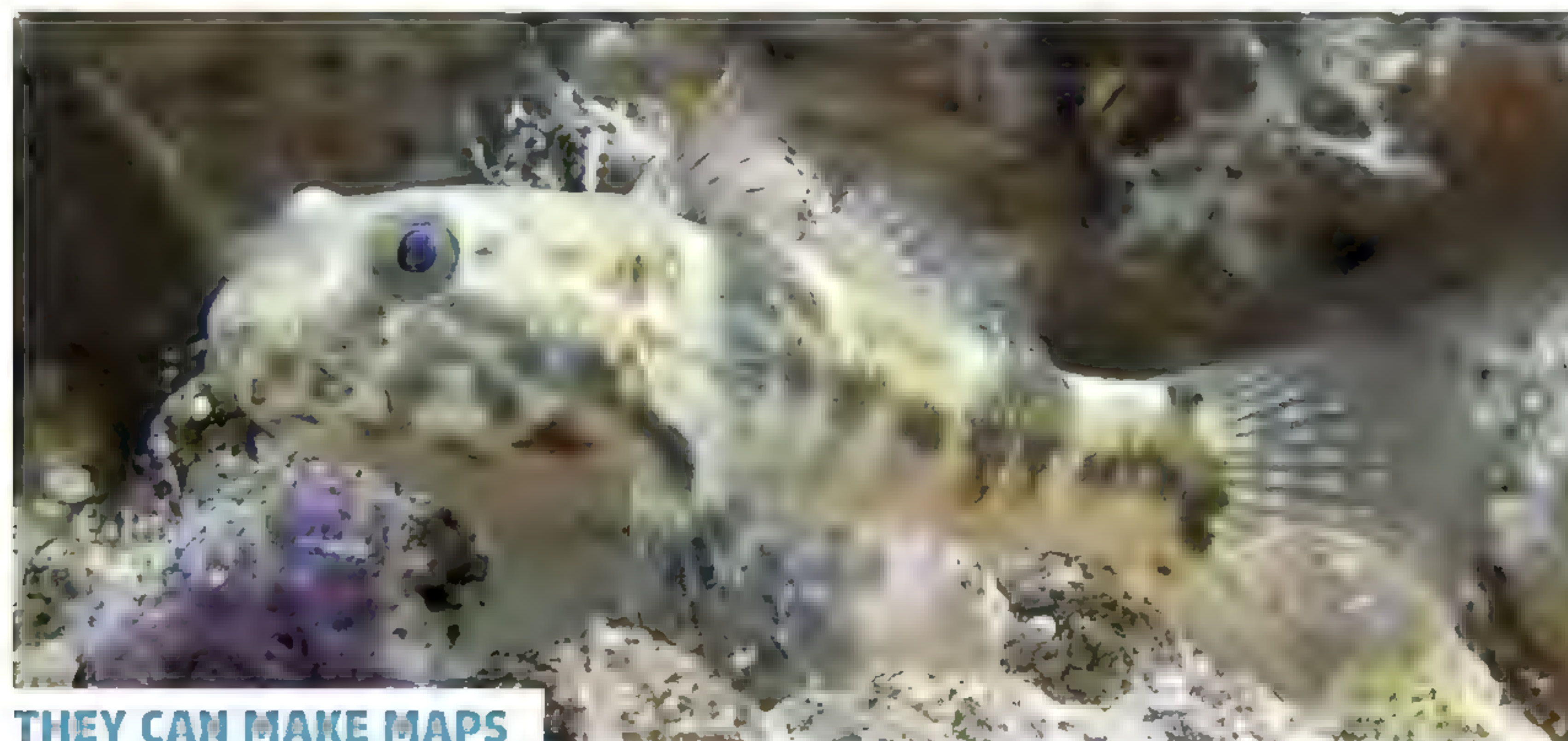
4: GOLDFISH HAVE A THREE-SECOND MEMORY

Wrong! Goldfish remember things for months. Feed your pet goldfish at one end of their tank each morning and the opposite each evening, and they'll quickly learn where to wait.



5: GOLDFISH ONLY LIVE FOR A COUPLE OF YEARS

Not true. In fact, the average lifespan of a captive goldfish is 5 to 10 years, and if they're carefully looked after they can live well into their 30s or 40s.



THEY CAN MAKE MAPS

Along the shores of the Gulf of Mexico live small fish called frillfin gobies. Swimming around at high tide they memorise features of the seabed and figure out where rockpools will form when the water recedes. At low tide, if a goby gets stuck with a predator in a pool, it knows which emergency escape route to take. It leaps in precisely the right direction to land in a neighbouring pool. When scientists remove these fish and then return them to their territories weeks later, the gobies still remember their mental maps and jump to safety.

LEFT: Not just a pretty face: these frillfin gobies can create mental maps of their territories, both above and below the waterline. What's more, they can remember them for weeks at a time

ABOVE RIGHT: Cleaner wrasse, like the one seen here in the mouth of an Indian Ocean oriental sweetlips, are capable of remembering individual fish and know what services to give them – rather like your friendly hairdresser

RIGHT: Archerfish seem to understand physics, adjusting their water jets to compensate for the way that light bends as it passes from water to air



THEY CHEAT

If you want proof that fish have more than the fabled three-second memory, look no further than cleaner wrasse. Every day, they pick parasites and dead skin from hundreds of other fish – and they remember each individual fish and adjust their services accordingly.

Scuba-diving scientists have spent hundreds of hours watching cleaner wrasse at work on coral reefs. They've seen that when large predators such as groupers show up the wrasse offer an honest service. But when they're cleaning harmless herbivores, like parrotfish, the wrasse will sometimes cheat. Instead of removing parasites, they slurp slime from the fish's skin. Not only is slime more nutritious than parasites, but it also contains sunscreen, which stops the wrasse getting sunburnt. Even when it cheats, a wrasse apologises by massaging the other fish with its fins and persuading them not to swim off in a huff.

THEY RECOGNISE FACES


It might strike you as an odd thing to do, but scientists at the University of Queensland and the University of Oxford have taught archerfish to recognise human faces. They positioned a computer screen above an aquarium tank and trained the fish to spit water at a particular face, giving them food whenever they hit the right target. When they were shown dozens of other faces, the archerfish kept on shooting at the ones they'd learned to associate with food.

Distinguishing between faces is a complex task involving spotting subtle differences in the same set of features (two eyes, a nose and a mouth). Obviously, archerfish didn't evolve a specific ability to recognise human faces, but the study shows that even without a big brain fish can recognise slight differences in their surroundings, presumably including other things that are important to them, such as predators and prey.



THEY MAKE TOOLS

Tool use is a sign of higher intelligence that various fish have. Archerfish use droplets of water as bullets to shoot insects off vegetation above the water's surface; they can even adjust the aim to compensate for the way light bends as it passes between air and water, and still hit their target.

A few years ago, researchers in Norway saw captive Atlantic cod inventing a new tool to feed themselves. Three cod, in two separate tanks, accidentally got their identification tags tangled in a string that released food from an automatic feeder. Beforehand, the cod had learned to pull the string with their mouths to get food. But these three cod worked out that it was much faster to deliberately hook their tags on the string then spin around and gobble the food. 

Dr Helen Scales is a marine biologist and science writer. Her latest book is *Eye Of The Shoal* (£16.99, Bloomsbury).

What TO DO, Where TO GO

Take the kids for a walk on science's wild side. These festivals are bursting with video games, explosions and cutting-edge tech (and not a text book in sight!).



ROYAL SOCIETY SUMMER SCIENCE EXHIBITION 2 - 8 JULY 2018

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MUSEUM





**YOU SPEND A THIRD
OF YOUR LIFE IN BED
(IF YOU'RE LUCKY!),
BUT SCIENTISTS
ARE ONLY JUST
BEGINNING TO
UNDERSTAND
WHAT GOES ON
BETWEEN THE
SHEETS. WE REVEAL
THE UNEXPECTED
DISCOVERIES BEING
MADE IN THE DEAD
OF NIGHT**

THE SURPRISING NEW **SCIENCE OF SLEEP**

WORDS: PROF ALICE GREGORY



WE CAN LEARN IN OUR SLEEP

Scientists know that weak traces of memories established during our waking lives are made more stable and enduring while we sleep. Yet what is perhaps less well understood and much more controversial is that we might be able to learn new information while we snooze. An example of this comes from a study in New York that focused on newborn babies. While they slept, a musical tone was played, then air was puffed towards their eyes. The babies soon came to expect the air puff, and would move their eyes upon hearing the tone. However, this was a simple example, and it is unlikely that more complex information could be learned in this way. What's more, numerous attempts to teach people new information during their sleep at other stages of life and using different experimental designs have largely failed. While sleep is clearly important for our learning and memory, frantically playing audiobooks the night before an important exam is not going to improve anyone's results. Sorry about that.

MORE SLEEP ISN'T ALWAYS BETTER FOR YOU

It's becoming clear that we need enough sleep to make the most of our time awake. There are recommendations for the amount of sleep we should get at different stages of life, with experts suggesting 8 to 10 hours for teenagers, and 7 to 9 hours for adults. But is it a problem if you get *more* sleep than the recommended amount? Well, a number of studies have highlighted associations between long sleep (which is defined in different ways, in different studies) and various problems such as obesity, cardiovascular disease and even early mortality.

But why might long sleep be associated with such problems? There are a number of possible explanations. Sleeping for excessive periods can be a sign of certain mental and physical disorders. What's more, when we are in bed excessively, our sleep can become more fragmented, so we may not get enough good-quality sleep. So does this all mean that long sleepers should restrict their time in the land of nod? That does not seem to be the case, according to the data we have to date. However, researchers need to establish why these associations exist if we want to use this information to improve our health and wellbeing.

Chances are if you're reading this then you probably feel like you don't get enough sleep. But did you know that too much sleep can make you ill? Or that a cup of coffee before bed isn't necessarily a bad thing? Cutting-edge sleep research is throwing up all kinds of surprises when it comes to our slumber...



SLEEP CAN HELP TREAT MENTAL HEALTH

We've known for a long time that disturbed sleep can be a feature of various psychological disorders. For example, insomnia (difficulties nodding off or staying asleep) and hypersomnia (excessive sleepiness) are listed among the criteria for diagnosing depression.

What's more novel is that addressing sleep problems might help prevent or resolve other psychological difficulties. Studies looking at children who are experiencing sleep-disordered breathing, for example, have found that removing adenoids and tonsils to improve night-time breathing is linked with fewer symptoms of attention deficit hyperactivity disorder (ADHD). Furthermore, a study led by researchers from the University of Oxford found that when insomniac students were given cognitive behavioural therapy (CBT) along with standard treatment, they experienced reduced insomnia, paranoia, hallucinations, anxiety and depression, compared to those who did not receive CBT.



OLDER PEOPLE ARE LESS AFFECTED BY BLUE LIGHT

There has been a lot of recent discussion about blue light and sleep. Blue light is the type of light that we can see outside on a stunning summer's day, and is also emitted by many phones and tablets. This type of light has been given particular attention because it can suppress the hormone melatonin, which our bodies produce when the Sun goes down to make us feel sleepy (for more on melatonin, turn to p25). Therefore, if we look at the blue light of our tablets late at night, our bodies might be missing a cue that it is time to sleep. The upside of blue light is that it can be helpful at certain times of day, increasing arousal and alertness when needed and helping to set the body clock.

What is less well-known is that the effect of blue light might vary at different stages of life. For example, the lenses of the eyes can yellow over time due to the accumulation of pigment, which can lead to less blue light being passed to our retinas. But before any older adults out there use this as an excuse to play with their tablets in bed, remember that these devices are likely to lead wakefulness and so this is difficult to justify as a bedtime activity.

SLEEP IS A COMMUNAL ACTIVITY

Many of us think of sleep as a solitary pastime. This view is often shared by researchers, who tend to study people alone in sleep laboratories. However, there are many reasons to think of sleep in the context of our families and our community.

For example, the majority of adults sleep with someone else, so in order to fully understand someone's sleep patterns it's important to think about their partner's nocturnal habits too. Likewise, children's sleep patterns can only really be understood when we look at the bedtimes that parents set, and their expectations of their kids overnight.

Our sleep timing changes throughout our lives, with adolescents tending to stay up late at night, and older adults going to bed early, for example. It has been proposed that one advantage of this is to ensure that someone is always awake to help keep an eye out for the wider group – it makes sense to only sleep if we feel safe. In fact, loneliness has actually been linked to poorer sleep. A similar explanation has been provided to account for the genetic differences that are associated with sleep timing (whether we are an early bird or a night owl).

"Many of us think of sleep as a solitary pastime. This view is often shared by researchers... yet the majority of adults sleep with someone else"

THERE MIGHT NOT BE A SLEEPLESSNESS EPIDEMIC

It's pretty clear that we don't get enough sleep, with many of us struggling to obtain the recommended seven to nine hours. However, what is less certain is whether this situation is new. Prof Malcolm von Schantz from the University of Surrey examined societies on the cusp of electrification, and it appears that the introduction of electricity is linked to going to bed later – yet this doesn't directly translate into less sleep. Furthermore, when considering sleep data over the recent decades, it is unclear whether sleep length has changed. Regardless, Dr Kristen Knutson from Northwestern University has pointed out that the effects of less sleep might be different now. For example, if sleeping less is associated with increased appetite, then it's not a problem if your job is physically active or you have limited access to calories. However, it may be more of a issue for people who have a sedate lifestyle – like those of us who are stuck at our desks all day – with easy access to calorific snacks.



GETTY X4



SLEEP DISORDERS COULD EXPLAIN ALIEN ABDUCTIONS

Sleep research could explain the paranormal. Someone might describe waking up at night finding they are unable to move, often with a strong sense that something, like an alien or demon, is present. Researchers have found that 'sleep paralysis' might be an explanation for these scary experiences. During an episode of sleep paralysis, we may wake up and open our eyes, but certain normal features of REM sleep – such as paralysis and dreams – continue. Sufferers of a condition known as 'exploding

head syndrome' have also been known to attribute the experience to the paranormal. Exploding head syndrome typically involves someone hearing a loud noise just as they are falling asleep. The most likely explanation is that when we fall asleep a part of the brain called the reticular formation inhibits our ability to hear, move and see. But in the case of exploding head syndrome, the auditory neurons all fire up instead of shutting down, leading to banging noises.



SLEEP TIPS ARE NOT STRAIGHTFORWARD

There are lots of tips to increase our chances of a good night's sleep, and avoiding caffeine tops the list. However, sleep researchers don't consider caffeine to be all bad. Not only can it increase alertness, but it can be used as a successful treatment for sleep apnoea (a disorder where breathing may stop for seconds at a time) in premature babies.

Another key tip is that getting exercise might help us nod off, but many people avoid working out in the evening due to concerns that it might interfere with sleep. Yet studies suggest that evening exercise is not problematic for our sleep, and we should go ahead if that's the time that suits us.

The virtues of a nap have been widely publicised, and include leaving us

refreshed, reducing stress and enhancing wellbeing. Some people are quite taken by the 'nappuccino' where they down a coffee and then go for a nap, in the hope that they will wake up raring to go. Yet naps can be problematic for those suffering from insomnia, who may then find it even more difficult to sleep at night. Over the years, we have been told to keep naps

short to avoid sleep inertia, which is a groggy state sometimes experienced upon waking. However, a recent review has highlighted that even a short nap can sometimes lead to this undesirable state. It is important that we take time to fully wake up after a snooze, in order to ensure a safe transition back to a hectic working day. ■



Dr Alice Gregory is a psychology professor at Goldsmiths University. Her new book, *Nodding Off: The Science Of Sleep From Cradle To Grave*, is out now (£16.99, Bloomsbury)

BBC FOCUS READER SURVEY

Welcome to our reader survey. This is your chance to tell us what you think about *BBC Focus* magazine, and help shape how it evolves in the future. The more we understand about your hobbies and interests, likes and dislikes, the more relevant and enjoyable we can make *BBC Focus* for you. Please return your completed questionnaire by 1 July 2018 to the Freepost address supplied at the end, or alternatively you can fill the survey in online at sciencefocus.com/readersurvey UK residents who return a completed questionnaire have the opportunity to enter our prize draw for a chance to win one of four £100 Amazon vouchers; please see our T&Cs on p72 for more information. We look forward to hearing from you.

Daniel Bennett
Editor



A. MAGAZINE READING BEHAVIOUR

1. How often do you read *BBC Focus*?

- ☐ 1 Always – I subscribe
☐ 2 Always – I don't subscribe, but I buy every issue
☐ 3 Almost always
☐ 4 Quite often
☐ 5 Occasionally
☐ 6 Not in the last 12 months
☐ 7 This is my first issue (go to Q8)

2. How long have you been reading *BBC Focus* for?

- ☐ 1 Less than a year (go to Q5)
☐ 2 Between 1 and 2 years
☐ 3 Between 2 and 5 years
☐ 4 Between 5 and 10 years
☐ 5 More than 10 years

3. Compared to a few years ago, are you buying *BBC Focus*

- ☐ 1 More often
☐ 2 Less often
☐ 3 Same as always
☐ 4 I read someone else's copy

4. Compared to a year ago, how do you feel about *BBC Focus* now?

- ☐ 1 The magazine has improved considerably
☐ 2 The magazine has improved a little
☐ 3 It is more or less the same as a year ago
☐ 4 The magazine has got a little worse
☐ 5 The magazine has got considerably worse

5. Thinking about an average issue of *BBC Focus*, how many other people read or look at your copy for longer than two minutes?

- ☐ 1 Nobody else (go to Q7)
☐ 2 1-2 people
☐ 3 3-4 people
☐ 4 5 or more people

6. And who has read or looked at any of your copies of *BBC Focus* for longer than two minutes? Please select all that apply

- ☐ 1 My partner
☐ 2 Friends
☐ 3 Colleagues
☐ 4 Children aged over 18
☐ 5 Children aged 16-18
☐ 6 Children aged under 16
☐ 7 Other family member
☐ 8 Other

7. On average, how long do you spend reading an issue of *BBC Focus*?

- ☐ 1 Under 30 minutes
☐ 2 Between 30 minutes and 1 hour
☐ 3 Between 1 and 2 hours
☐ 4 Between 2 and 3 hours
☐ 5 Between 3 and 4 hours
☐ 6 Between 4 and 5 hours
☐ 7 More than 5 hours

8. How often do you read the following magazines?

	1	2	3	4	5	6	7
<i>BBC Focus Collection</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>BBC History Magazine</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>BBC Sky at Night Magazine</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>BBC Top Gear Magazine</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>BBC Wildlife Magazine</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>How It Works</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>National Geographic</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>New Scientist</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>New Scientist Collections</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Stuff</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>T3</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<i>Wired</i>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

B. SCIENCE AND TECHNOLOGY INTERESTS

9. How much do you agree or disagree with the following statements?

	1	2	3	4	5
I prefer to understand a topic in depth	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I prefer to know a little bit about a broad range of topics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
General knowledge is important to me	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I'm naturally curious	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I count science among my hobbies	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I have a specific interest in certain scientific topic/s	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I'm interested in all scientific topics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

10. How interested are you in reading about the following topics? Please select one answer per row

	1	2	3	4	5
Artificial intelligence	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chemistry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cosmology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Engineering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Environment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Genetics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Health	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Medical advances	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Nature	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Our future	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Physics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Psychology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Robotics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Space exploration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. Which of the following are you interested in, or have you done in the last 12 months?

	1	2	3
Attending a science/tech-related talk/lecture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Attending a science/tech-related event/festival	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Going to a science/tech museum/exhibition	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Going on a science-related holiday e.g. to see the Northern Lights	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Visiting a place of scientific interest e.g. a National Park/conservation area	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

12. Do you share your interest in science and technology with anyone in your everyday life?

- ☐ 1 Yes, multiple people
☐ 2 Yes, one person
☐ 3 No

13. Have you taken, or are you interested in taking, any of the following qualifications?

	1	2	3
Science/tech subject GCSE	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Science/tech subject A Level	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Science/tech bachelor's/master's degree	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Science/tech doctorate or equivalent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Science/tech evening course	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Science/tech short course or non-formal qualification	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

C. MAGAZINE EVALUATION

14. Which of the following best describes why you read *BBC Focus* magazine? Please select ONE main reason and as many secondary reasons as apply

	Main reason	Secondary reasons
I love science	<input type="checkbox"/>	<input type="checkbox"/>
I love technology	<input type="checkbox"/>	<input type="checkbox"/>
To stay up-to-date on discoveries and innovations	<input type="checkbox"/>	<input type="checkbox"/>
To learn/educate myself	<input type="checkbox"/>	<input type="checkbox"/>
For entertainment	<input type="checkbox"/>	<input type="checkbox"/>
For a connection to the world of science	<input type="checkbox"/>	<input type="checkbox"/>
As a source of general knowledge	<input type="checkbox"/>	<input type="checkbox"/>

15. How much do you agree or disagree with the following statements about *BBC Focus*?

	1	2	3	4	5	6
It's written by experts	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It's really informative	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It's entertaining	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It's a high-quality magazine	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The design is attractive	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
It's good value for money	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The website is a good reflection of the magazine	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I don't consider it a science magazine	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
I only read the magazine if the main cover subject interests me	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The name matches the content well	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The name stands out on the newsstand	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The covers tend to look a bit cluttered	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

16. If you knew someone interested in science and technology, on a scale of 0 to 10 (where 0 is not at all likely and 10 is extremely likely) how likely would you be to recommend *BBC Focus* to them?

	0	1	2	3	4	5	6	7	8	9	10
Not at all likely	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10 Extremely likely	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

17. How much did you enjoy this issue of *BBC Focus*?

- ☐ 1 Very much
☐ 2 Quite a lot
☐ 3 Not very much
☐ 4 Not at all
☐ 5 Haven't read this issue yet (Go to Q19)

READER SURVEY

WIN one of four **amazon.co.uk** gift certificate **Worth £100**

18. Listed below are all the articles in this issue of *BBC Focus*. For each item, please select the column that comes closest to your opinion

	Very interesting 1	Quite interesting 2	Not that interesting 3	Not at all interesting 4	Did not read 5
Eye opener p6	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Reply p10	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Discoveries p13	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Michael Mosley p25	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Innovations p27	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Inside the dinosaur's mind p38	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Time travel: a user's guide p50	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Deep thought p56	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
The surprising science of sleep p65	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Tricks of the mind p73	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Q&A p79	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Helen Czerski p89	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Out there p90	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Crossword p96	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
My life scientific p98	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

19. Would you like to see more of any of the following type of content? Please select all that apply

Eye openers	<input type="checkbox"/>	1
Discoveries section	<input type="checkbox"/>	2
Innovations section	<input type="checkbox"/>	3
Reply section	<input type="checkbox"/>	4
Q&A section	<input type="checkbox"/>	5
Out There section	<input type="checkbox"/>	6
Long-form reads	<input type="checkbox"/>	7
Short, digestible articles	<input type="checkbox"/>	8

20. What do you think about *BBC Focus*'s coverage of the following topics?

	I'd like more 1	It's about right 2	I'd like less 3
Artificial intelligence	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Chemistry	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cosmology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Engineering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Environment	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Genetics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Health	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Medical advances	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Nature	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Our future	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Physics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Psychology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Robotics	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Space exploration	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Technology	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

21. What do you think about the level of articles that are featured in *BBC Focus*?

Much too academic	<input type="checkbox"/>	1
A bit too academic	<input type="checkbox"/>	2
About right	<input type="checkbox"/>	3
A bit too simplistic	<input type="checkbox"/>	4
Much too simplistic	<input type="checkbox"/>	5

22. Has reading *BBC Focus* ever led you to do any of the following? Please select all that apply

Visit sciencefocus.com	<input type="checkbox"/>	01
Attend a science event/exhibition	<input type="checkbox"/>	02
Buy a tech product/gadget	<input type="checkbox"/>	03
Buy another product	<input type="checkbox"/>	04
Seek more information on a product seen in the magazine	<input type="checkbox"/>	05
Discuss an advert/article with someone else	<input type="checkbox"/>	06
Visit a company's website	<input type="checkbox"/>	07
Contact an advertiser	<input type="checkbox"/>	08
Research an article further	<input type="checkbox"/>	09
Take a course	<input type="checkbox"/>	10
Take a trip to a place of interest	<input type="checkbox"/>	11

If you didn't select 'research an article further', please go to Q24

23. If *BBC Focus* offered resources providing additional/in-depth information about a specific topic, would you be interested in any of the following? Please select all that apply

Online tutorials	<input type="checkbox"/>	01
Online courses	<input type="checkbox"/>	02
Printed tutorials	<input type="checkbox"/>	03
Printed courses	<input type="checkbox"/>	04
Video guides	<input type="checkbox"/>	05
Talks/lectures	<input type="checkbox"/>	06
Expert essays	<input type="checkbox"/>	07
Reading lists	<input type="checkbox"/>	08
Further research	<input type="checkbox"/>	09
Programme recommendations	<input type="checkbox"/>	10
Podcasts	<input type="checkbox"/>	11
An app	<input type="checkbox"/>	12
Other	<input type="checkbox"/>	

24. On average, how often do you visit the *BBC Focus* website (sciencefocus.com)?

More than once a day	<input type="checkbox"/>	1
Once a day	<input type="checkbox"/>	2
About 2-3 times a week	<input type="checkbox"/>	3
Once a week	<input type="checkbox"/>	4
Once every couple of weeks	<input type="checkbox"/>	5
Once a month	<input type="checkbox"/>	6
Every 2-3 months	<input type="checkbox"/>	7
Less often	<input type="checkbox"/>	8
Never visited it	<input type="checkbox"/>	9

25. On average, how often do you listen to the *BBC Focus* podcast (Science Focus podcast)?

Every week	<input type="checkbox"/>	1
Regularly (at least once a month)	<input type="checkbox"/>	2
Occasionally (once every few months)	<input type="checkbox"/>	3
Never, but I'm aware of it	<input type="checkbox"/>	4
Never - I wasn't aware of it	<input type="checkbox"/>	5

26. Do you have any comments you'd like to add?

D. ABOUT YOU

27. Which age group are you in?

Under 16*	<input type="checkbox"/>	1	45-54	<input type="checkbox"/>	5
16-24	<input type="checkbox"/>	2	55-64	<input type="checkbox"/>	6
25-34	<input type="checkbox"/>	3	65+	<input type="checkbox"/>	7
35-44	<input type="checkbox"/>	4			

*Unfortunately the prize draw is only open to adults aged 16+

28. Are you?

Male	<input type="checkbox"/>	1	Female	<input type="checkbox"/>	2	Other	<input type="checkbox"/>	3
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29. If you have a child/children, which age group/s do they fit into? Please select all that apply

Under 2	<input type="checkbox"/>	1	Between 12-15	<input type="checkbox"/>	4
Between 2-5	<input type="checkbox"/>	2	16+ living at home	<input type="checkbox"/>	5
Between 6-11	<input type="checkbox"/>	3	16+ flown the nest	<input type="checkbox"/>	6

30. Which of these best describes the main wage earner's occupation in your household? If retired, please tick the box describing their former occupation

High managerial, administrative or professional	<input type="checkbox"/>	1
Intermediate managerial, administrative or professional	<input type="checkbox"/>	2
Supervisory, clerical and junior managerial, administrative or professional	<input type="checkbox"/>	3
Skilled manual	<input type="checkbox"/>	4
Semi-skilled or unskilled manual	<input type="checkbox"/>	5
Unemployed	<input type="checkbox"/>	6
Student	<input type="checkbox"/>	7

31. What is your current employment status?

Employed full-time	<input type="checkbox"/>	1
Employed part-time	<input type="checkbox"/>	2
Studying full-time	<input type="checkbox"/>	3
Studying part-time	<input type="checkbox"/>	4
Retired	<input type="checkbox"/>	5
Not working/unable to work	<input type="checkbox"/>	6

32. What is your household income before tax?

Under £20,000	<input type="checkbox"/>	1
£20,000-£29,999	<input type="checkbox"/>	2
£30,000-£39,999	<input type="checkbox"/>	3
£40,000-£49,999	<input type="checkbox"/>	4
£50,000-£69,999	<input type="checkbox"/>	5
£70,000-£99,999	<input type="checkbox"/>	6
£100,000-£149,999	<input type="checkbox"/>	7
Over £150,000	<input type="checkbox"/>	8
Prefer not to say	<input type="checkbox"/>	9

33. Is your home?

Mortgaged	<input type="checkbox"/>	1
Owned outright	<input type="checkbox"/>	2
Rented	<input type="checkbox"/>	3
Other	<input type="checkbox"/>	4

Thank you for taking the time to complete this questionnaire!

If you'd like to be included in our free prize draw for a chance to win one of four Amazon vouchers worth £100, please remember to fill in your name and email address or telephone number clearly in the spaces below.

Name

Phone

Email

Please return your questionnaire by 1 July 2018 to:

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TRICKS OF THE MIND

Psychologists are starting to figure out why we get false memories, and it turns out that they might even be useful...

WORDS: PHILIP BALL



Dr Rob Nash had been excited to meet the former British newsreader Trevor McDonald at his sister's graduation ceremony.

"He was getting some kind of honorary degree," Nash recalls. "I was sat right at the back, so all I could see was that he was wearing this awful, garishly multicoloured graduation robe. His speech seemed to go on and on, but afterwards I got the chance to meet him in person."

But Nash – a psychologist at Aston University – discovered a few years later that McDonald hadn't been at that event at all. In fact, Nash realised that even he wasn't at his sister's graduation. He'd invented the whole thing.

False memories like this are common. Of course, we all misremember things, but false memories can be rich in detail; not so much mistakes as elaborate fantasies. I recall a book of piano pieces that I used to play in my youth – a compilation of tunes with the wistful romanticism of Chopin and Fauré. I can still almost remember how some of them went and I'd love to find that book again. But I know I won't, because I've had to gradually accept the truth: I made it up.

In a recent interview in *The Times*, novelist Ian McEwan described a similar false memory, of an "incredibly beautiful" novella that he was convinced he'd written and then stowed somewhere in a drawer after he'd moved house. He looked all over the place for the work. "I saw it in my mind's eye, the folder, the pages, the drawer it was in," McEwan tells me. But there was no escaping the truth. "There was no gap in which this work could have been written – my time was fully accounted for. It was a kind of haunting."

Nash might have expected to be better at spotting his false memory, though – he specialises in studying them. But even his expertise and experience wasn't enough to make him immune.

So why do we get false memories in the first place? Over the past decade or so, psychologists like Nash have started to suspect that, far from being a kind of useless

"False memories can be rich in detail; not so much mistakes as elaborate fantasies"

BELOW. Do you remember the time Trevor McDonald attended that graduation ceremony?

mental spasm, false memories might actually have some benefits. It seems that they're able to improve our mental processing: they can help us to think and may be a surprisingly handy part of our cognitive toolbox.

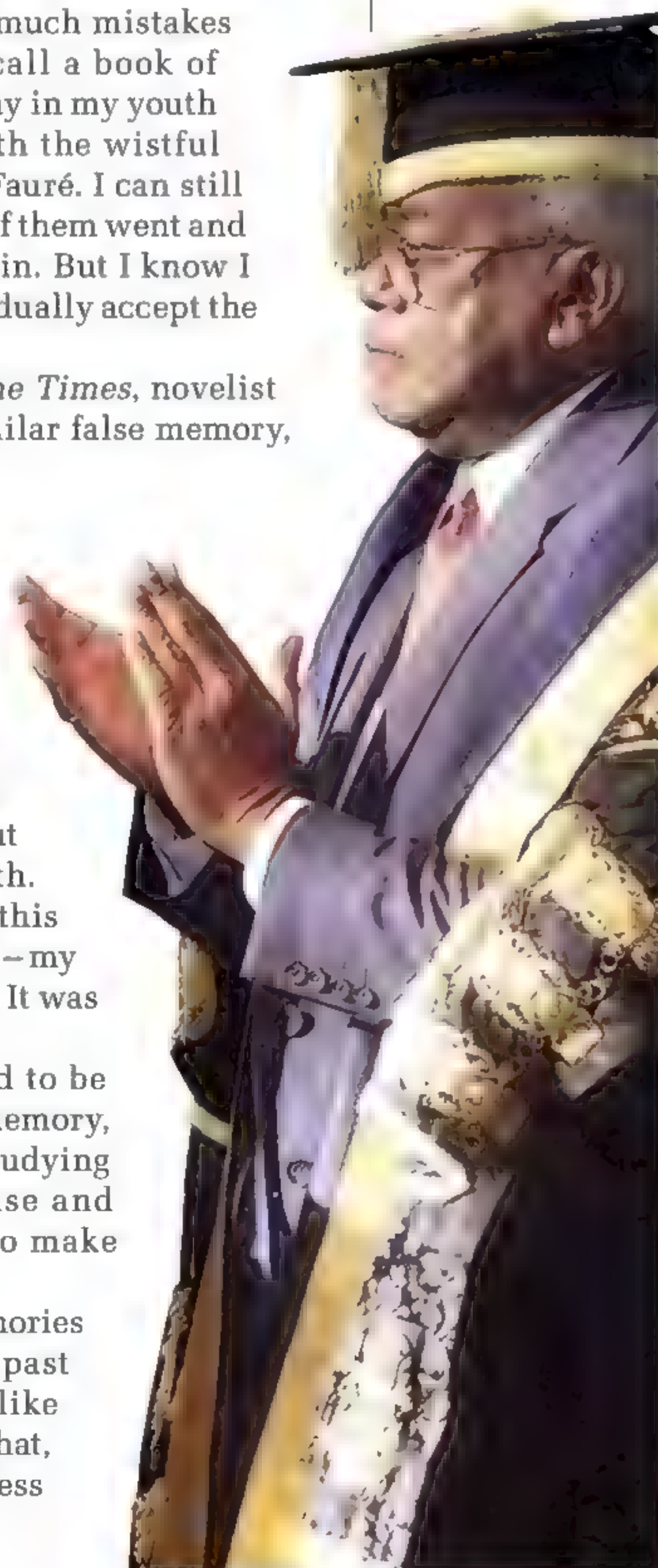
REMEMBER, REMEMBER?

Remembering, says Nash, isn't a matter of looking up a fact in a mental filing cabinet. "It's more like telling stories," he says – we forget and invent details. It's hard to know when these don't map onto reality because, as far as we can tell, "memories are our reality." Despite decades of research, we still can't distinguish true memories from false ones unless we can independently verify or falsify the remembered facts, which is either impossible or hardly worth the effort (why should I care if I had porridge last Wednesday – or was it Thursday?).

What's more, says psychologist Prof Mark Howe of City, University of London, "false memories are produced by the same processes as true memories – they are reconstructed from whatever mental imprint remains of the original experience." It's not surprising, then, that it's relatively easy to implant false memories in people by furnishing them with fake evidence. In 2009, Nash and his colleagues filmed subjects performing certain actions and then, days later, showed them the footage after it has been digitally doctored to include some actions they hadn't actually carried out. Over half of the participants said they recalled – clearly and vividly – doing those things.

In other experiments conducted by Prof Fiona Gabbert and colleagues at the University of Aberdeen back in the early 2000s, pairs of participants were shown footage in which a young woman stole a wallet – but only one of the pair saw it from a perspective in which the theft was actually visible. Yet when the pair subsequently discussed the events between them, around 60 per cent of those who hadn't seen the theft directly swore that they had.

Gabbert also showed people faked CCTV footage of a shop robbery and had them discuss what they'd seen. One of the participants was a stooge primed





to introduce false ideas: the thief had a gun, right? He was wearing a leather jacket, wasn't he? (No and no.) About three in four people later confidently recounted these 'facts' when questioned. This susceptibility – what psychologists call memory conformity – is a big problem for witness testimonies at crime or accident scenes. "The consequences of memory conformity in legal arenas can be far-reaching and serious," says Gabbert. Indeed, false memories have become a legal battlefield in crime cases.

Such contagious suggestibility can lead to mass delusions, as became clear when Nelson Mandela died in 2013 and many people admitted they thought he'd died in prison during the 1980s and could even remember his funeral – a phenomenon now dubbed the Mandela Effect. Rather less sombrely, there's the strange case of Walkers crisps packets. Many people are convinced (wrongly) that the green and

blue colours for, respectively, the Salt & Vinegar and Cheese & Onion flavours used to be reversed.

Gabbert suggests that this mass effect might explain sightings of the Loch Ness monster. "People know exactly what that monster 'should' look like," she says. "They've got a lot of visual imagery they can very easily access when they're interpreting something [they've seen]."

IMAGINED FUTURES

Memory is clearly an evolutionarily adaptive trait: remembering the past helps us prepare for the future. So false memories must be a bad thing, right? If we remember things wrongly, we'll have inaccurate future expectations. It turns out that it's not that simple. Some cognitive scientists think that cognition works to prepare us for imagined future scenarios: if I do *this*, then *that* will happen. The process relies on gathering and



ABOVE: If many people's memories are to be believed, Nelson Mandela died in prison during the 1980s

RIGHT: Floating debris or a famous but elusive creature? A clear idea of what you expect to see may shape your recollection of what you think you saw

● retaining information about how the environment responds to our actions. In this case, sometimes a plausible guess, expressed mentally as a false memory of what happened last time, is better than having no clue at all. In this way, a false memory can suggest alternative scenarios for decision-making, priming the mind to be better at problem solving. After all, these 'memories' might not be wrong about what *would* happen in a given situation, but only about our imagined past role in such a case.

Over the past several years, Howe and his colleagues have demonstrated cognitive benefits of false memories in tests where participants were presented with lists of words (brush, gum, paste) that



were all related to a non-presented word or 'critical lure' (in this case, tooth). When this critical lure was falsely remembered as having been present on the list, performance was enhanced on a subsequent problem-solving task where the lure word was the solution – as if the mind were saying to itself "Ah, I know this one because I saw the word on the last list." Howe and his colleagues also found that false memories could give the same performance boost in tests on lists of words linked by analogy ('tooth is to brush, as hair is to wash'). The effect works for all ages, from children to older adults.

INACCURATE BUT USEFUL

So false memories can help us to spot associations and connections – they heighten our vigilance – and it might not matter if we get the right answer for the wrong reason (in this case, falsely believing that we saw a word on a list). To put it another way, the most useful memory might not be the most accurate one.

Memory illusions might do more than assist factual cognition. For example, they may play a socially adaptive role: we can sometimes unknowingly edit our memories, Howe says, to match what others think or feel, helping us feel more connected to them. "Distortions of our past can serve to nurture social relationships by facilitating empathy and intimacy with others," he says. In this vein,

Nash says that his father remembered spending time with his grandfather, even though the grandfather was dead before the grandson was born.

In other words, rose-tinted glasses aren't always a bad thing. "If we see our past in a more positive light than we did initially, that gives us a more positive image of ourselves, leading to a greater likelihood of interacting with others and maintaining social relationships," says Howe. And such illusions can increase confidence to good effect: if you remember



THE DARK SIDE OF FALSE MEMORIES

There's an ongoing debate in psychology about the nature of false memories, and their implications for criminal cases. Can false memories be imagined out of thin air, or do they need some kind of 'real-life' seed? And if false memories can materialise out of nothing, what does that mean for the testimonies of defendants, victims and eyewitnesses?

To take one example, in the 1990s, there was a panic that psychotherapy patients were being furnished with false memories of childhood sexual abuse. Could the seeds of false memories of abuse be sown when therapists dig for forgotten childhood traumas as explanations of psychological problems in later life?

"Although some people can and do have reasonably accurate memories for childhood abuse, there are circumstances under which suggestive interviewing or therapy can create memories of abuse where there are none," says psychologist Prof Mark Howe. In 2015, two psychologists found that interviews with volunteers using repetitive, suggestive questioning led to 70 per cent of them falsely remembering having committed a

crime in early adolescence that led to police contact. Their reported memories were rich in detail, despite being demonstrably untrue.

But clinical psychologist Prof Chris Brewin of University College London questions whether reputable therapists work in such a way as to accidentally seed false memories. He also says that false memories are not easily spun out of nothing. "People probably wouldn't be having these memories without a connection to *something*," he points out. Details might be misremembered, but Brewin says there's usually a "grain of truth" in such recollections. The question is whether that grain of truth is an actual event or just the memory of a book, TV show or movie, or something someone told you.

This aspect of false memory remains highly contentious. Yet Brewin says that clinical specialists agree that recovered memories exist and that "they can be true, false or a mixture of the two." He and Prof Bernice Andrews argue that "either uncritically accepting false memories, or disbelieving genuine recovered memories, has the potential to do immense harm."

"Distortions of our past can serve to nurture social relationships by facilitating empathy and intimacy"

that you solved a problem easily last time, you're more likely to do that this time – even if the truth is that last time you actually struggled like mad. For the brain, a false sense of confidence could be a risk worth taking.

THE CREATIVE MIND

The idea that false memories can sometimes have positive value is gaining ground. As Nash's imagined Trevor McDonald encounter shows, they can be highly inventive – and he suspects that they could be an offshoot of the human aptitude for creativity. "I'm sure that most art and music contains ideas and motifs borrowed and recombined from many other sources," he says. "So one could draw parallels between the construction of memories and of creative ideas."

Initially, Ian McEwan was tempted to find such a creative response to his imaginary novella. "It was perfect in every way," he told *The Times*, adding that if he wanted to recreate that perfection then "I'll have to write it."

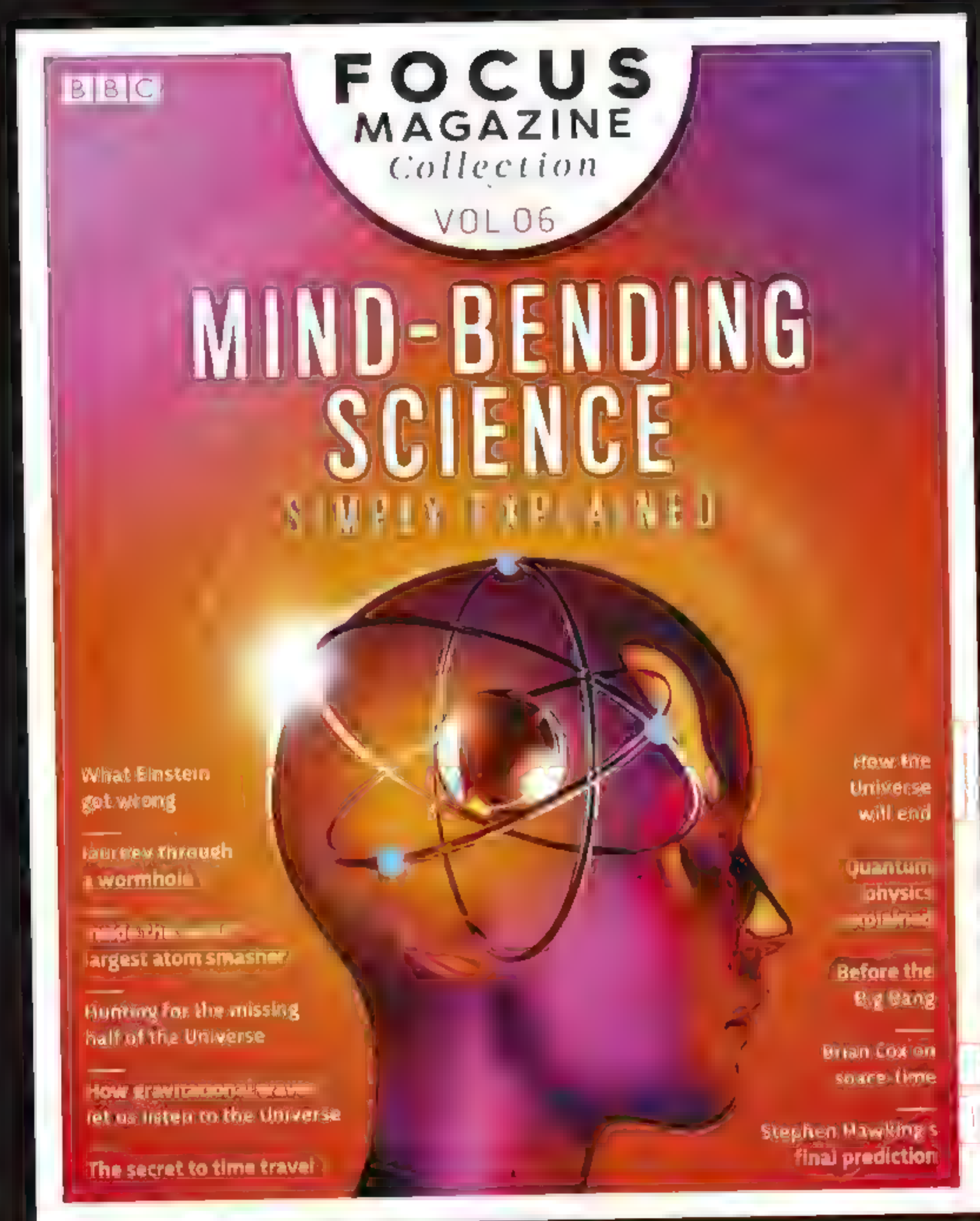
But for a memory that's actually false, that's easier said than done. "By describing it in public and then seeing articles about it," he now tells me wistfully, "the ghost of this non-existent masterpiece has fled." **G**

Philip Ball is a science writer and presenter of *Science Stories* on BBC Radio 4. His latest book is *Beyond Weird* (£17.99, Bodley Head)

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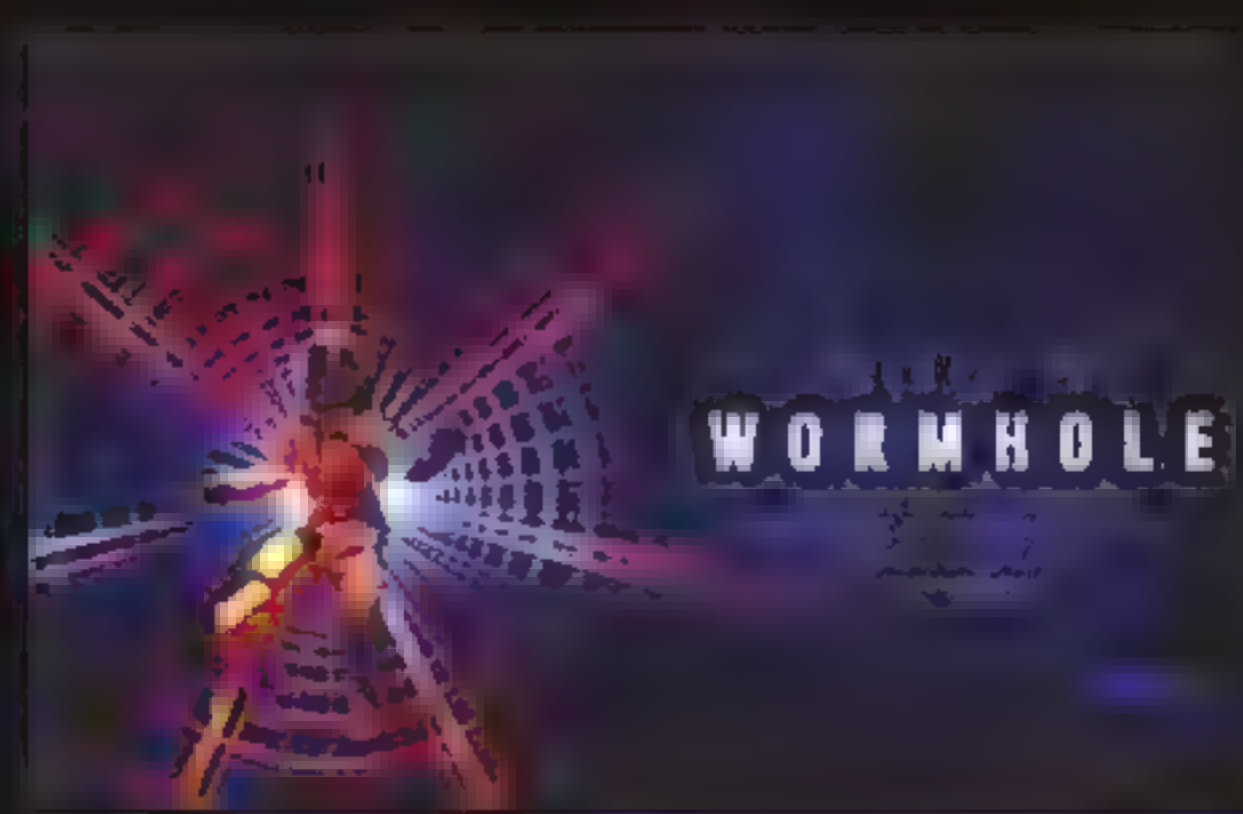
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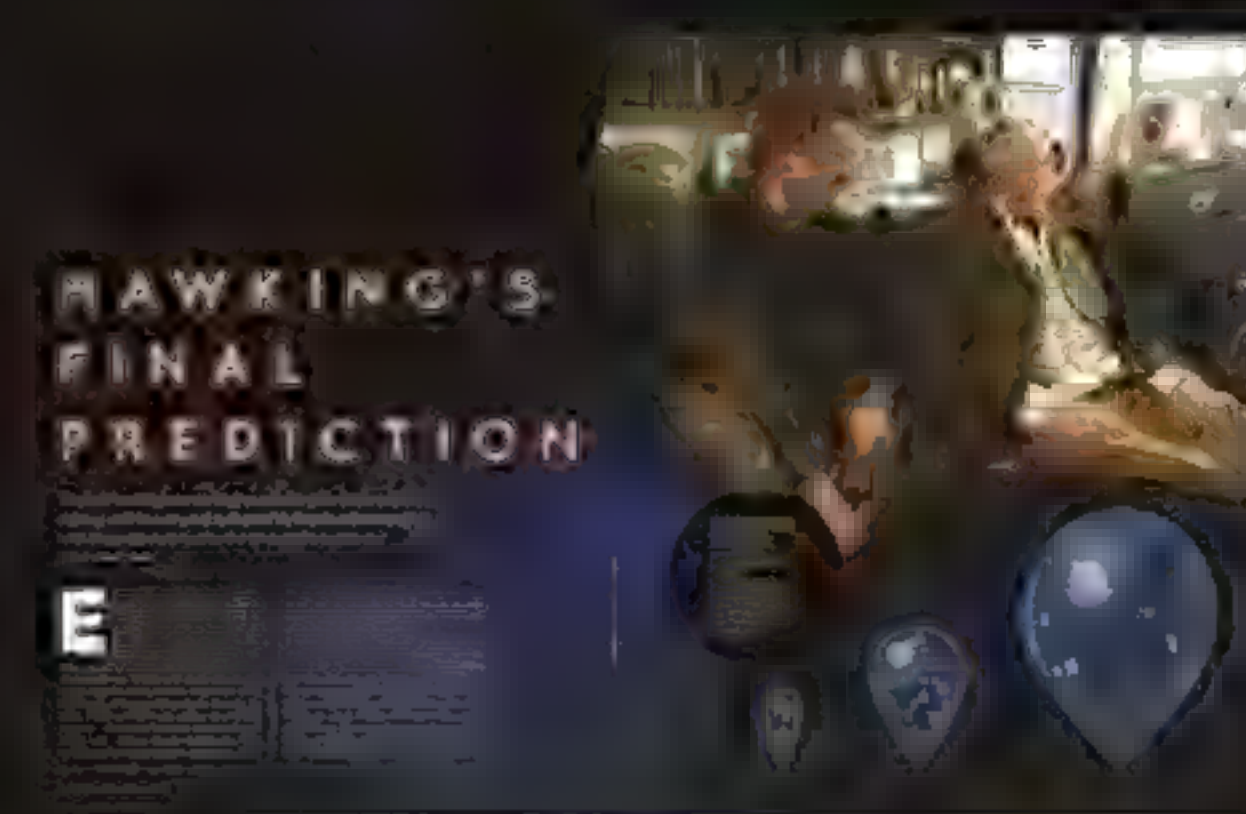
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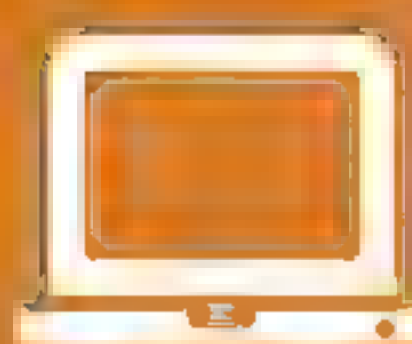
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YOUR QUESTIONS ANSWERED

JULY 2018

EDITED BY JAMES LLOYD



Mike the chicken became a celebrity, appearing in magazines and touring the US

For how long can a chicken survive without its head?

KANIKA AHUJA, WINCHESTER

In the 1940s in the US, a chicken called Mike lived for 18 months without a head. He had been almost completely beheaded with an axe, but crucially the jugular vein and most of the brainstem were left intact. This left just enough brain function for essential functions, like breathing, and Mike was fed with an eyedropper through the stump of his neck. In Thailand, in March this year, a similar case was reported, and the strong-stomached can even watch a video of the headless chicken online. But for more normal, complete beheadings, a chicken will die of blood loss in a matter of minutes. **TV**



What's the biological difference between an identical twin and a clone?

EDIE SUDLOW, WOKINGHAM

Identical twins have the same DNA as each other, but different from their parents. A clone, however, only has one parent and has exactly the same DNA as that parent. But even so, a clone isn't a perfect copy. We now know that the way genes are turned on and off is greatly affected by the environment. Twins

share the same uterus during development so they are exposed to the same mix of nutrients and hormones. A clone grows in a different uterus and at a different time from the parent animal, so it isn't necessarily identical to the way its parent looked at the same age – even at birth. **LV**

IN NUMBERS

30

The number of identical twins born in the UK each year is estimated to be around 30. This is based on the fact that there are about 100,000 identical twins in the world, and the UK population is about 60 million.

52,800

The number of clones created in the UK each year is estimated to be around 52,800. This is based on the fact that there are about 100,000 clones in the world, and the UK population is about 60 million.

500,000

The number of clones created in the UK each year is estimated to be around 500,000. This is based on the fact that there are about 100,000 clones in the world, and the UK population is about 60 million.

With the rise of superbugs, are we about to find out what it would have been like to live in a world without antibiotics?

DAN SWAIN, BERKSHIRE

Antibiotic-resistant bacteria, or 'superbugs', are certainly a serious problem. It takes 15 years for a new antibiotic to be developed and tested, but just 10 years of widespread use before bacteria resistant to that drug become common. No new classes of antibiotics have been found since 1984, and drug companies are less interested in looking for new ones because treatments for cancer and heart disease are more lucrative.

But things will never get as bad as they were before the world had antibiotics. Better hygiene and sanitation has vastly reduced the incidence of infectious diseases and helped to contain the spread of

antibiotic-resistant strains. In Europe, 400,000 people a year are infected with superbugs, but only 25,000 (6 per cent) of these cases are fatal. This many deaths still sounds like a lot, but it's tiny compared to the number that died before we had antibiotics, when half of all deaths were caused by pneumonia, flu, tuberculosis, gastrointestinal infection and diphtheria. The superbug problem is serious and getting worse, but antibiotics still save a huge number of lives. In the future, we may need to move away from antibiotics altogether and use bacteria-killing viruses known as 'phages' to target the superbugs. **LV**

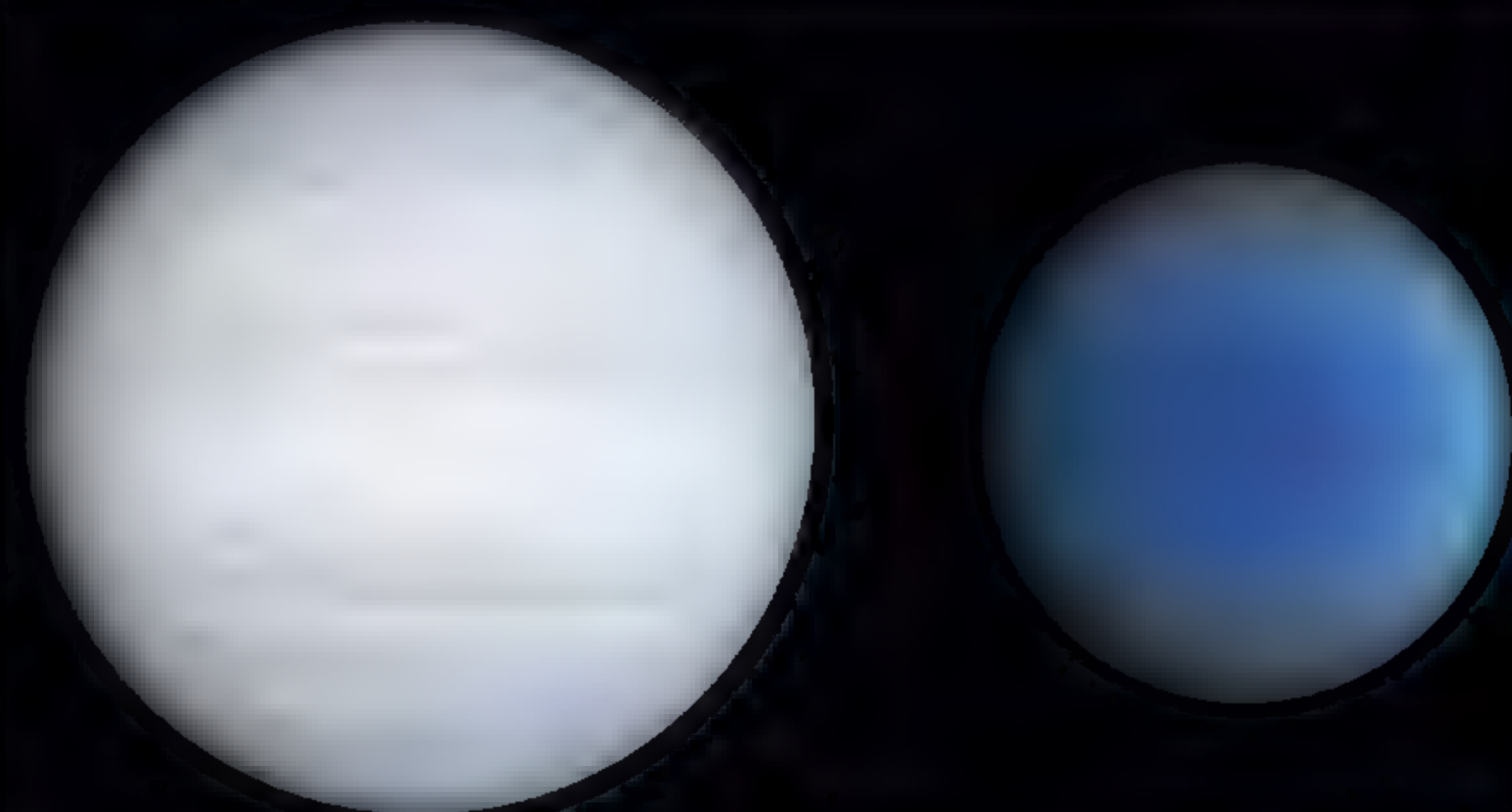


Phages, seen here attacking a bacterium, are types of virus that could be used to target superbugs

GETTY X3, NASA ILLUSTRATIONS RAJA LOCKEY

Could a gas moon exist?

HN, TORONTO



Just like gas planets, a gas moon would need to be a lot bigger than its rocky counterparts – if it were too small then it wouldn't have enough gravity to hold on to large amounts of light gases such as hydrogen and helium. However, this means that a 'gas moon' would likely be of comparable size to its parent planet, and so would more appropriately be called a 'binary planet'. Such gaseous binary planets are possible, but probably extremely rare because planet formation would usually result in the two objects merging or deflecting each other to separate orbits. So we haven't spotted one yet! **AGW**

THE THOUGHT EXPERIMENT



What colour is water?

ASHLEY MARTIN, HAMPSHIRE

We usually think of water as a colourless liquid, but it's not true. When white light is shone through a long column of the stuff, the liquid is faintly blueish. That's because the water mops up the longer, redder wavelengths of light, leaving the bluer wavelengths unscathed. As with so many of its properties, however, water does this in a bizarre way, with the light energy being absorbed by its V-shaped H_2O molecules, which start to vibrate as a result. **RM**

What would happen if everyone on the planet suddenly went vegan?

JASPER WILSON, WISBECH



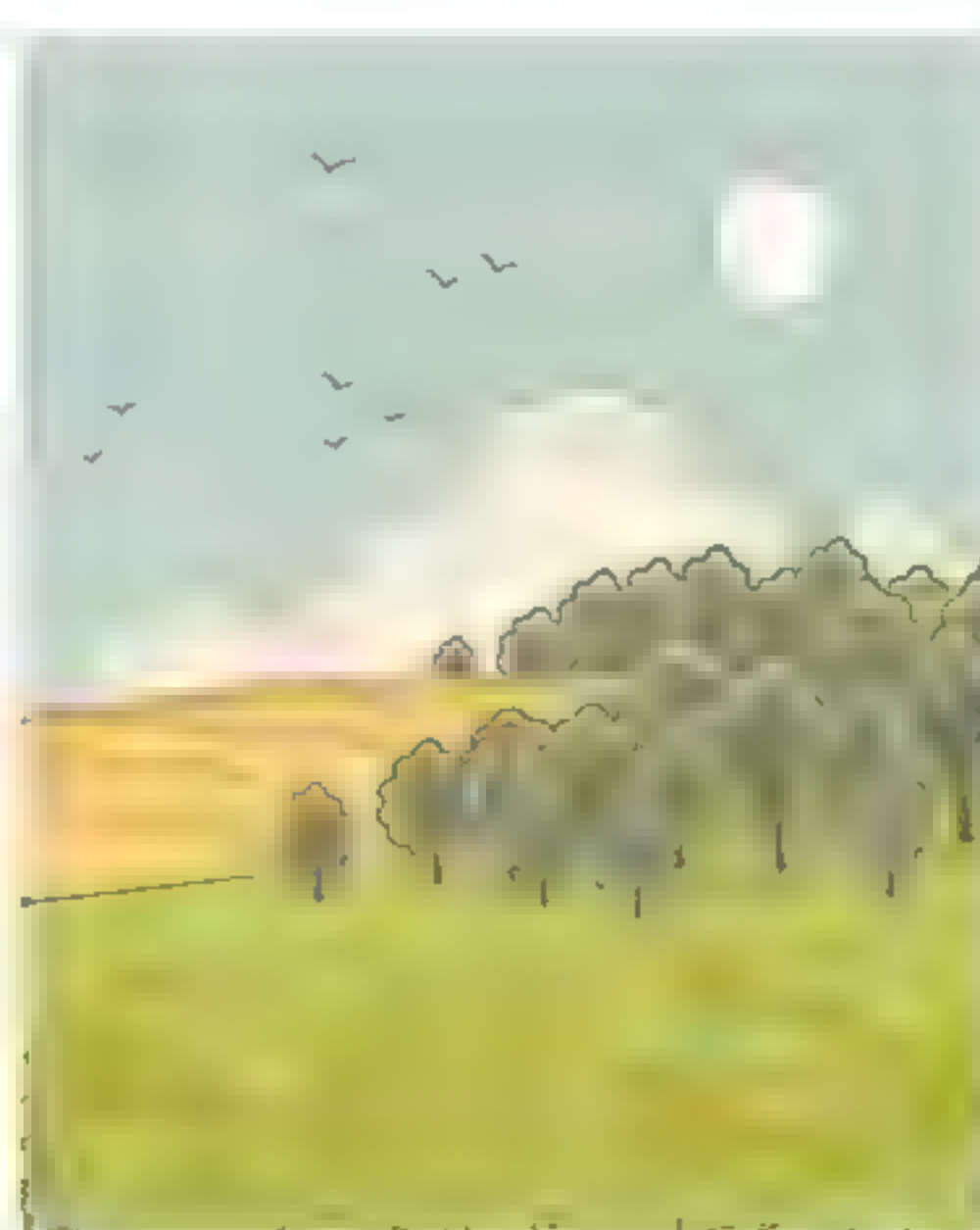
1. ANIMAL SANCTUARIES

Veganism seeks to exclude all cruelty to animals. Simply opening the farm gates to the existing stock of 3.5 billion grazing animals and 19 billion chickens wouldn't work. Most would starve to death or be eaten by predators. Instead, farms would need to be converted into sanctuaries for the remaining natural lives of the animals.



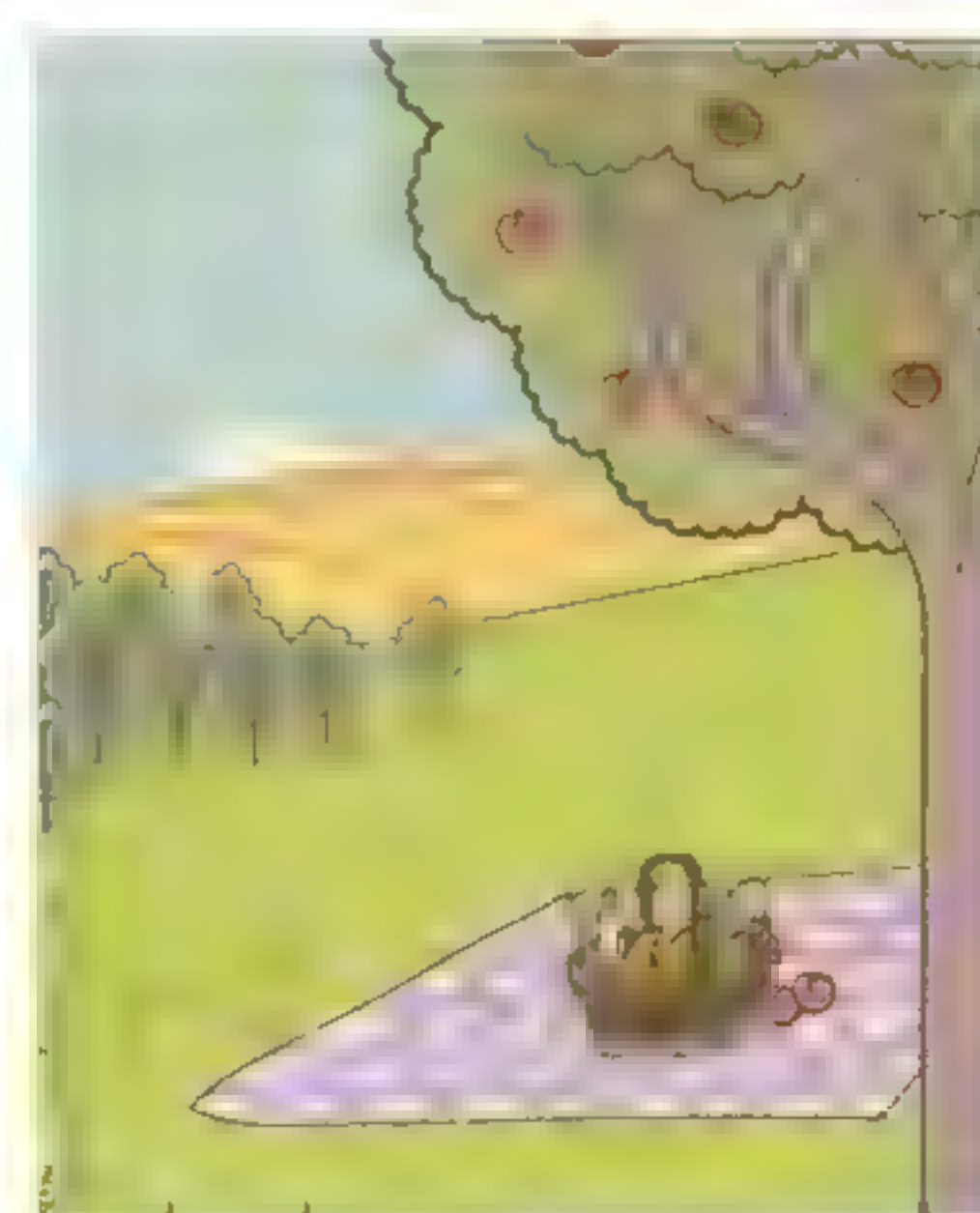
2. EMISSIONS

Food production is responsible for a quarter of all greenhouse gas emissions, mostly from cows burping methane. Methane is such a potent greenhouse gas that a global switch to plant-based diets would cut emissions from food production by 28 per cent – that's the equivalent of India going carbon neutral.



3. LAND USE

Currently, 68 per cent of farmland is used for livestock. Planting a fifth of this with crops would produce the same amount of food as all the animals. This would leave 26 million square kilometres spare – an area 1.5 times the size of Russia – that could be planted with meadow or forest, to improve biodiversity.



4. HEALTH

If we all gave up meat, around eight million fewer people would die each year, as a result of lower levels of heart disease, strokes and cancer. But most crops have lower levels of micronutrients per calorie than meat – especially vitamins A, B12 and D, and some essential fatty acids. Crops would have to be adjusted to avoid malnutrition.



Incoming projectile
vomit in 3... 2... 1...

Why do we make eye contact with strangers as we pass them?

SAMUEL CHAABANE, HOVE

Eye contact is a fundamental part of human social interactions – even two-day-old babies prefer to look at those faces that are gazing straight at them. If someone is looking at you, it indicates social interest and a possible desire to communicate, but of course you cannot know if someone is looking unless you, in turn, attempt to meet their gaze. Hence why when we pass strangers we will often automatically glance at their faces. A field study on a university campus in the US found that making eye contact with strangers leaves us feeling more socially connected, whereas if someone avoids our gaze, we are more likely to feel disconnected. This feeling is captured beautifully by the German expression ‘wie Luft behandeln’ – to be looked at as though air. **q**

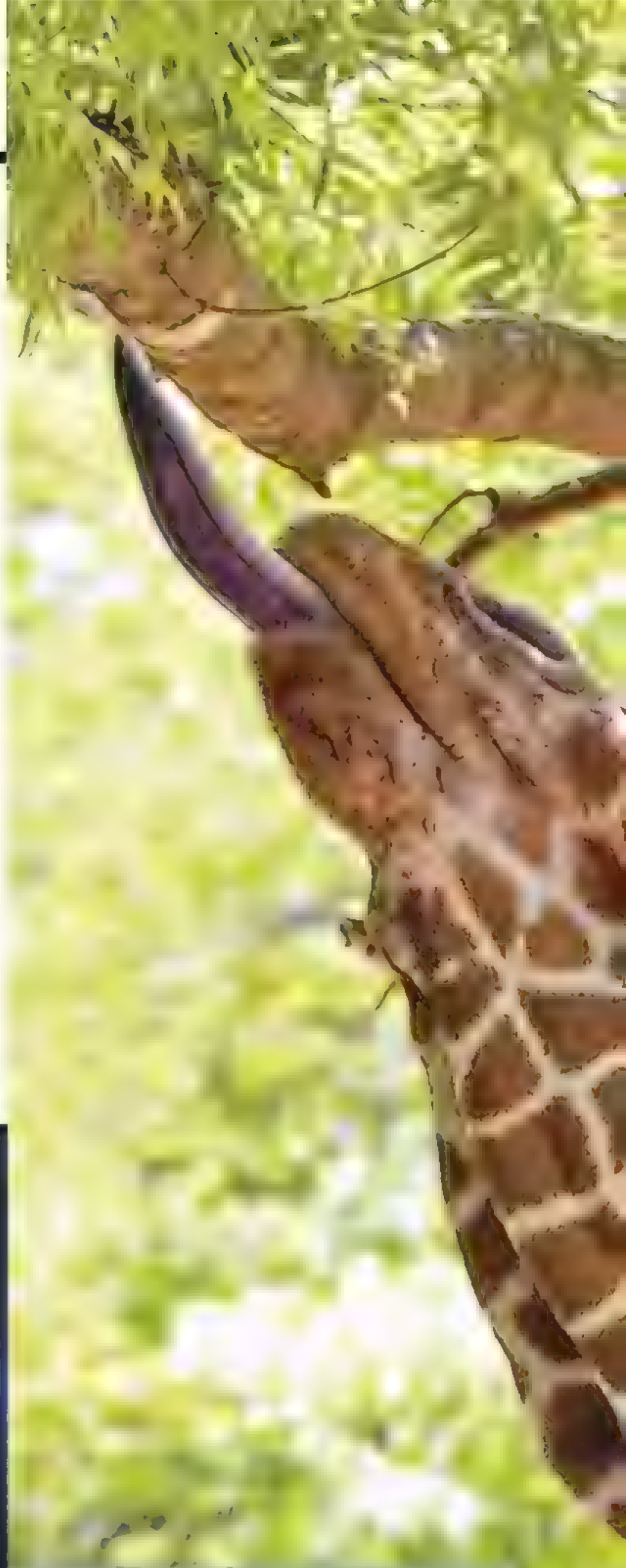


How big could a black hole get?

VANESSA TAYLOR, NOTTINGHAM

There is no theoretical upper limit to the mass of a black hole. However, astronomers have noted that the ultra-massive black holes (UMBHs) found in the cores of some galaxies never seem to exceed about 10 billion solar masses. This is exactly what we'd expect from the rate at which we know black holes

grow, given the time that's elapsed since the Big Bang. Furthermore, recent studies suggest that UMBHs cannot physically grow much beyond this anyway, since they would then begin to disrupt the accretion discs that feed them, choking the source of new material. **Aca**



Why do giraffes have purple tongues?

EMMA-LOUISE HALLIDAY, BEDFORD

If you've ever been lucky enough to be licked by a giraffe, you'll notice that their 50cm-long tongues can appear purple, bluish or almost black in colour. This is due to the density of dark 'melanin' colour pigments in them. There's still no definitive explanation for this, but the leading theory is that the melanin provides extra UV protection, preventing their delicate tongues from getting sunburnt as they feed up high. **cc**



How do you get milk from nuts?

JON FRIEDMAN, PORTSMOUTH



Commercially, nut milks such as almond milk are made by grinding the nuts to an extremely fine paste and then mixing thoroughly with water. This dissolves the nuts' sugars and proteins into the water and disperses their fat content as tiny globules that are fine enough to remain in suspension. Vitamins and minerals are added later. You can make simple almond milk for yourself by putting almond butter and water in a blender. **LV**

If we only have one trachea, why do we have two nostrils?

STEVE PURVES, PRESTON



Two eyes, two ears, two nostrils. We need our doubles for stereoscopic vision, stereo sound, and super smelling. Our nostrils are separated by a septum, in effect giving us two noses. Most of the time, one nostril allows less air to pass through than the other, with the nasal flow switching every few hours. The slower airflow is caused by the tissue inside swelling with increased blood flow. We smell using sensory cells high up in the nose, and some odour chemicals need more time than others to bind to these receptors. So a low-airflow nostril gives slow-acting odours more time to be detected, giving us a greater range of smell. **ED**

WHO REALLY DISCOVERED?

THE LAW OF GRAVITY?



Isaac Newton (1643–1726) and Galileo Galilei (1564–1642) are both credited with discovering the laws of gravity.

Newton's law of universal gravitation states that every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

Galileo's experiments on inclined planes showed that the acceleration of an object is constant, regardless of its mass. This led to the discovery that the force of gravity is constant for all objects.

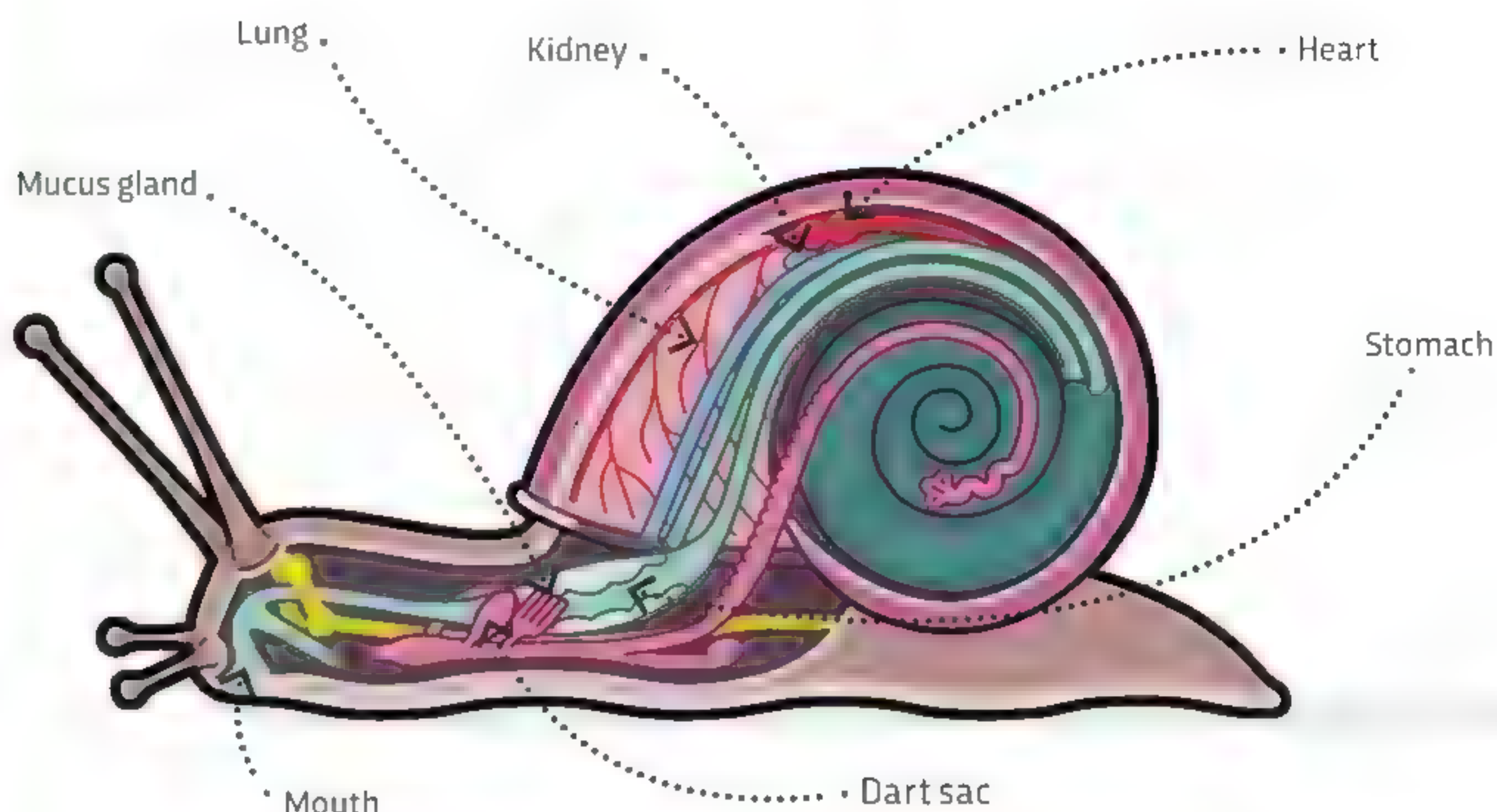
Newton's law of universal gravitation is a more general statement of the law of gravity.

Galileo's experiments on inclined planes showed that the acceleration of an object is constant, regardless of its mass. This led to the discovery that the force of gravity is constant for all objects.

Newton's law of universal gravitation is a more general statement of the law of gravity.

Why do slugs and snails produce a silver trail?

REBECCA SUTTON, MORECAMBE



The characteristic slime trail left by slugs and snails has some of the qualities of both a glue and a lubricant. It helps the creature glide forwards when pressure is lifted, or stick to surfaces when pressure is applied. It's made from a carbohydrate mucus and a 'hygroscopic' protein – meaning that it absorbs moisture from the air, helping to prevent it from evaporating.

The slime is secreted from a gland inside its 'foot', and the chemicals it contains are also important for communication. Interestingly, the medical community is now investigating the adhesive and elastic properties of this slime, with the hope that it might lead to a synthetic glue that's capable of repairing tissue damage. **cc**

If gold and silver were mixed together, what colour metal would you end up with?

ASHLEY MARTIN, HAMPSHIRE



Figure of a deer, moulded from electrum, dating back to the Thracian-Getan civilisation in the 4th Century BC

The naturally occurring alloy of gold and silver is commonly known as electrum. Its colour depends on the ratio of gold and silver in the mix: a whitish alloy appears below 50 per cent gold, turning to greenish yellow as the amount

of gold increases, and bright yellow at around 85 per cent gold. To get a wider range of colours, metallurgists and jewellers may add in a third metal. Introducing copper, for example, leads to reddish yellows and deeper brassy reds. **ML**



WHAT IS THIS?

Lava flow

Fast-moving lava from Hawaii's Kilauea volcano rushes across the countryside, destroying everything in its fiery path.

The volcano has been erupting continuously since 1985, but in early May this year an earthquake shook the land. Since then, lava has been spewing from fissures, including in residential areas, and more than 40 structures have been destroyed.



LIDAR creates a 'map' of a driverless car's surroundings

Would it be possible for autonomous cars to use echolocation like a bat in order to scan their surroundings?

RHYS ABUL, SOUTHAMPTON

Sending out sound waves and listening for their echo is a great way to detect obstacles in water – submarines can detect objects many kilometres away. But sound doesn't travel nearly so well in air. Bats can only detect objects up to 20 metres away, falling to around 2 metres in poor conditions. Light is less affected by atmospheric conditions, which is why self-driving cars use LIDAR ('light detection and ranging'), bouncing infrared laser light off objects in order to detect them. **PB**

Why don't flies fly in a straight line?

KENNETH BAILEY, BELLEVILLE



To escape from predators, flies have evolved a highly aerobatic flying style. Instead of turning by flapping harder with one wing than the other, they roll their body to one side and pull up, like a fighter pilot in a high-G turn. Random zig-zags like this make it much harder for birds to get a 'missile lock' on them. **tv**

WHAT CONNECTS...

PLAGUE AND EAU DE COLOGNE?

1.

Until bacteria were discovered in the 17th Century, infectious diseases were thought to be caused by noxious smells. The word 'malaria' comes from the Latin for 'bad air'.



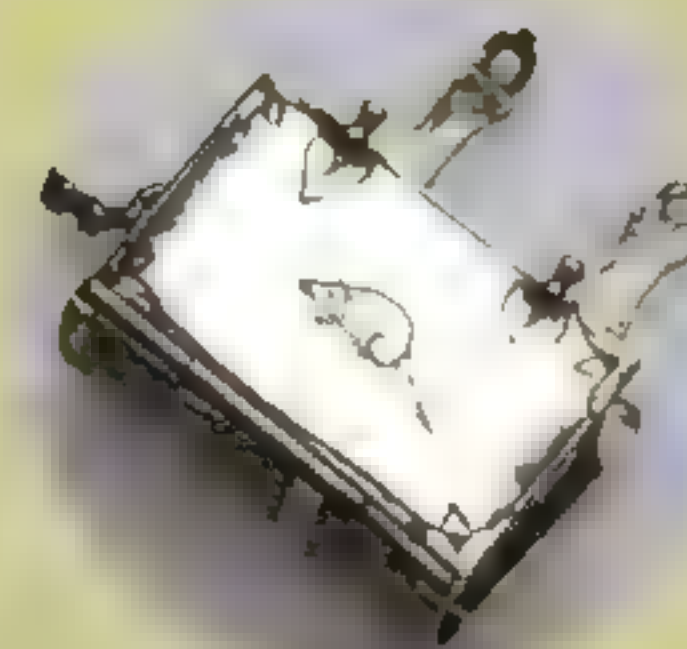
2.

During the Black Death in Europe in the 14th Century, towns and cities would build bonfires of scented wood to try and purify the air and drive away the disease.



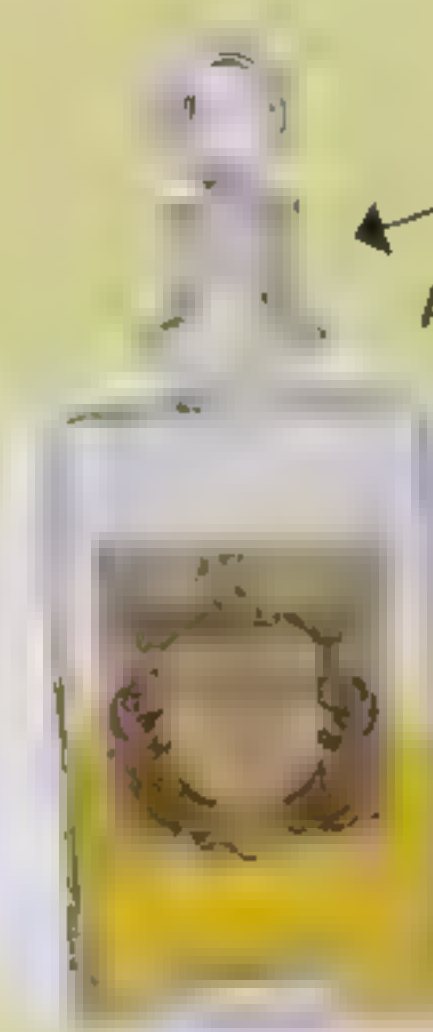
3.

For more portable protection, the rich carried their own vials, filled with strong-smelling plant essential oils. The word 'perfume' comes from the same root as the word 'fumigate'.



4.

As perfume became associated with wealth, an industry grew up in Europe to cater to changing fashions. The original citrus recipe of Eau de Cologne dates back to 1709.



CAN PLANTS TALK?

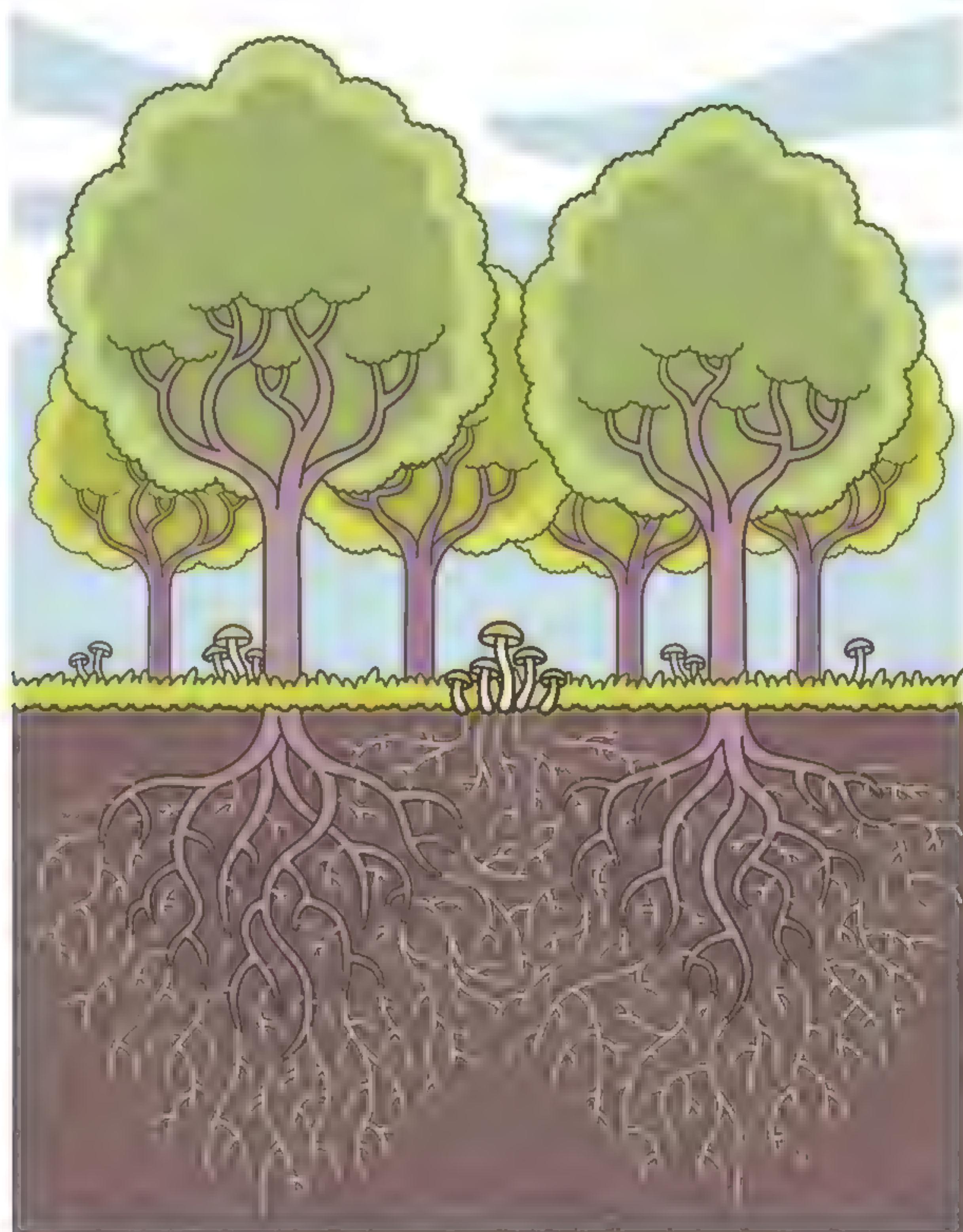
We teamed up with the folks behind BBC World Service's *CrowdScience* to answer your questions on one topic. You can tune in to *CrowdScience* every Friday evening on BBC World Service, or catch up online at bbcworldservice.com/crowdscience

Can plants talk to each other?

Plants may not seem particularly chatty, but there's a silent stream of information passing between them. Beneath the soil, the roots of most plants interact with tiny branching strands of fungi, known as mycorrhiza. It's a two-way deal: fungi provide nutrients from the soil, while the plants provide sugars made in their leaves through photosynthesis. But the fungi don't restrict their interactions to individual plants: they form a network that spans entire forests. Botanists now know that plants can pass nutrients and chemicals back and forth through this network, known as the 'Wood Wide Web'.

Can plants communicate with insects?

We've long known that flowering plants use colour and scent to attract insects, but scientists have recently discovered that flowers also use electricity to communicate with their pollinators. Flowers tend to have a negative electric charge, while bees tend to be positively charged. A 2013 study at the University of Bristol found that a bee's visit will change a flower's electric potential, which may be the flower's way of telling other bees that its nectar reserves have just been snaffled. What's more, some flowers are able to electrically 'fire' pollen at bees as they fly past, without even being touched.



What do plants talk about?

Plants use this fungal network to tell each other about the dangers around them. When a plant is infested with sap-sucking aphids or other insects, a chemical signal is produced which is transmitted through the Wood Wide Web. Nearby plants respond by pumping anti-insect toxins into their sap, reducing the chances of an attack. Family is important to plants, too. Mustard seedlings send signals that identify themselves to their siblings, helping them to grow without competing with each other for root space. But there's also a dark side to this network. The phantom orchid, for example, is known to hack the system in order to steal carbon from nearby trees.



Rory Galloway is the producer of *Do Plants Talk About Sex?* – an episode of *CrowdScience* airing on 29 June.



How do ocean tides create magnetic fields?

TOBY GRAHAM, SHREWSBURY

We're taught in science lessons that it's possible to create electric current by moving electrical conductors through magnetic fields. Known as Faraday's law of induction, it's the basic idea behind electricity generation in power stations. But shortly after discovering the effect in 1831, Michael Faraday wondered if it might lead to a natural source of electricity. To find out, he tried to detect the current produced by the electrically conducting river water flowing through the Earth's magnetic field under London's Waterloo Bridge. The experiment, conducted in January 1832, was a failure, but Faraday remained convinced the currents did exist – if only extremely weakly.

Earlier this year, a trio of ESA satellites called Swarm were able to detect electric currents generated in the world's oceans as they are dragged through the Earth's magnetic field by the gravitational pull of the Moon. These currents are then able to induce their own feeble magnetic fields – around 20,000 times weaker than the Earth's magnetic field. Mapping the oceans' magnetic signature required state-of-the-art equipment unimaginable in Faraday's time. But as well as vindicating the Victorian genius's claim, the research is expected to provide a whole new way to monitor the movements of the oceans. **RM**

QUESTION OF THE MONTH

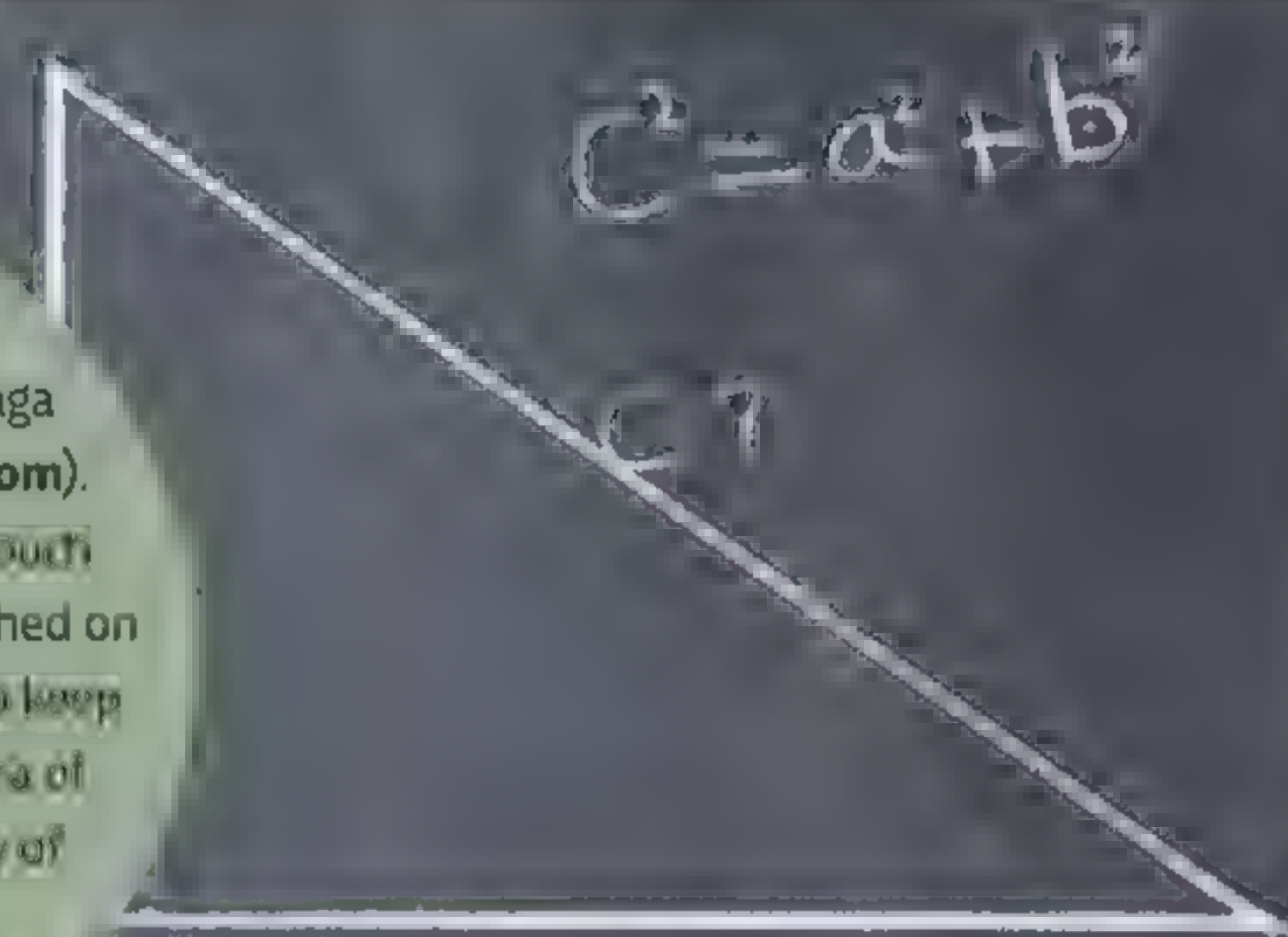
Was maths invented or discovered?

LEAH VICTORIA SMITH, HEREFORD

The fact that 1 plus 1 equals 2, or that there's an infinite number of primes, are truths about reality that held even before mathematicians knew about them. As such, they're discoveries – but they were made using techniques invented by mathematicians. For example, according to Pythagoras' theorem, the square of the hypotenuse of a right-angled triangle is equal to the sum of the squares of the other two sides. This is true for all right-angled triangles on a level surface, so it's a discovery. Showing it is true, however, requires the invention of a proof. And over the centuries, mathematicians have devised hundreds of different techniques capable of proving the theorem. In short, maths is both invented and discovered. **RM**

WINNER!

Leah Victoria Smith wins a Saga backpack (£59.95, stmfgoods.com). It features a suspended tech pouch that stops your laptop being bashed on the ground, is water repellent to keep your gear safe and the plethora of pockets means there's plenty of room for your stuff.



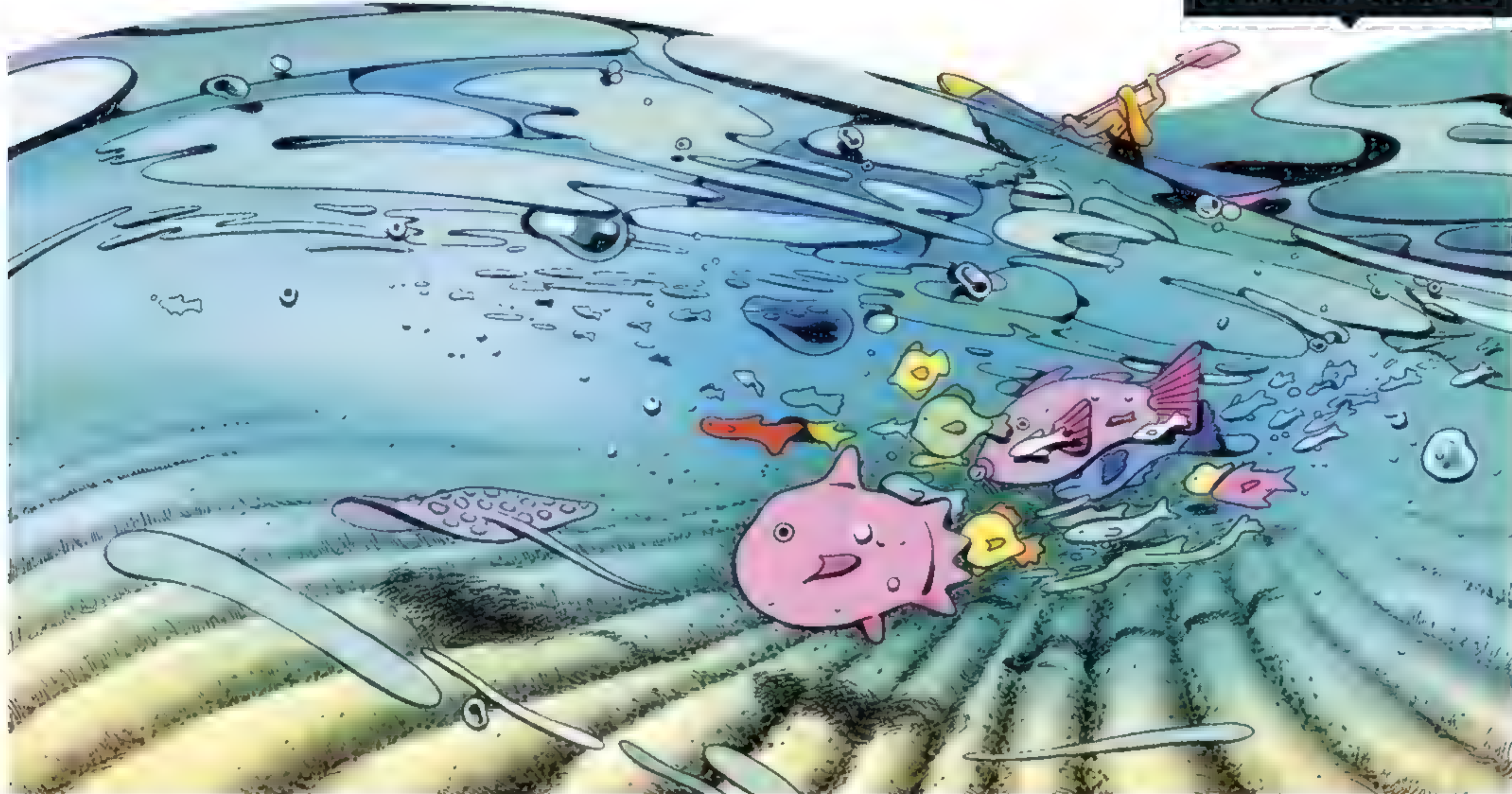
$$b^4$$

$$c^2 = 3^2 + 4^2$$

$$c^2 = 9 + 16$$

NEXT ISSUE:

Why do we find people who?



WHY DOES SAND FORM RIPPLES ON THE SEABED?

Summer is finally in full swing, and that means it's time to play outdoors. I spent a recent weekend paddling outrigger canoes along a beach in Dorset, and the lovely thing about a canoe is that you can float and watch the underwater world without disturbing it. The water was beautifully clear, and I started to pay attention to the sandy ripples on the seafloor, and especially how organised they were. When you think about it, a tidy pattern of ridges made of sand is a fairly strange thing, but they're such a familiar sight that we rarely ask the question: what are they doing there?

The ripples that I could see had their origin in the waves I was bobbing about on. Next time you see a gull parked on the ocean as waves go past, imagine drawing a line that follows the movement of the bird. It doesn't just go up and down as the wave goes past – it sways forwards and backwards too, following a circle. The water molecules beneath it are doing the same thing, and the circles get smaller as you go downwards through the water column. As the waves travel towards the beach, the circles are all lined up pointing at the shore, like hoops standing on end.

But as the sea gets shallower, there's no room for water to move downwards, so the circles get squished into lines, and right at the seafloor the water just rushes forwards and backwards, towards the beach and then away from it. Looking down from my canoe, I could see tiny fragments of seaweed doing just that, whooshing across the sand and back.

A ripple starts when that oscillating current glides over a bit of a bump so quickly that it can't flow smoothly over the top and so it generates a small eddy instead – a packet of rotating water just on the downstream side of the bump. The eddy picks up some sand from behind the bump, starting to excavate a trough by moving sand downstream. At the point where this sand settles out of the flow, you've got the start of the next ripple crest. And then during the second part of the wave cycle, the water rushes back the other way and the same thing happens on the other side, excavating another trough and building another peak with the same spacing. As the waves travel over the top, the ripples build until the sand rolling off the peaks halts the growth.

This is why the ripples were symmetrical – they were being formed

by an oscillating flow that was roughly the same in both directions. The separation of the ripple crests depends on the size of the wave circles and also the sand grain size, which is why the ripples all have the same spacing in any one place. If the tide is going in or coming out quickly, there might be a stronger flow in one direction than the other, making the ripples steeper on one side than the other.

The amazing thing about sand ripples is they're always being rebuilt. If the water movement stops, the ripples will crumble away, leaving no trace. The ripples you see are an indication of what's happening today, right here, and tomorrow they'll look different.

As I paddled along, I watched the waves splashing against the bow of my canoe, and imagined these mini sand-sculptures being built beneath me. The ocean is never still, and the building will never stop. **G**



DR HELEN CZERSKI

Helen is a physicist and BBC presenter. Her latest book is *Storm In A Teacup* (£18.99, Transworld)

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

JULY 2018

EDITED BY HELEN GLENNY

01

RHS HAMPTON COURT FLOWER SHOW

HAMPTON COURT PARK, LONDON
3-8 JULY 2018

GO GREEN

At this year's RHS Hampton Court Flower Show, quiet your thoughts in the tranquil Apeiron Garden. It was designed by Alex Rainford-Roberts, who was struck by the sense that her memories of her grandfather would live on after he died, which inspired her to create a meadow that exists and doesn't all at once. The result is a mirrored room containing an infinite garden, which is perfect for a moment alone.

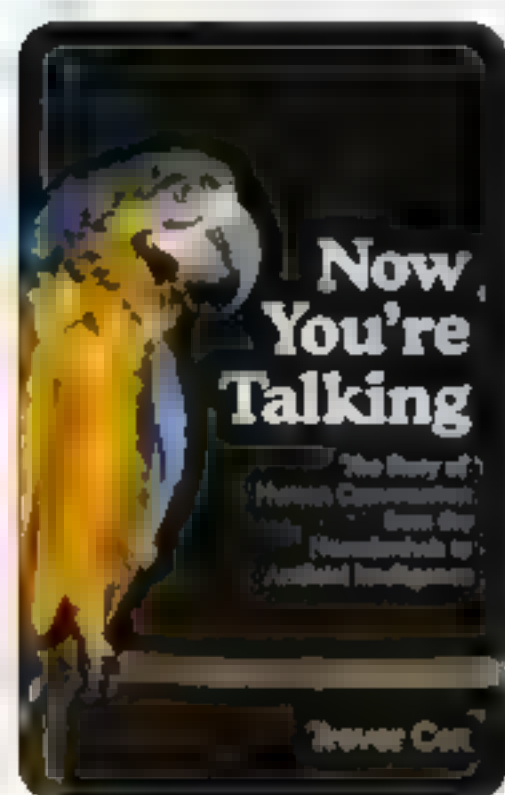
In other installations, you'll find plants that reduce pollution and improve air quality, and you can challenge your views on consumerism in an installation set aboard a cattle truck. Meanwhile, the South West Water Green Garden promotes the fact that rainwater is a precious resource, and wants to inspire others to implement water recycling in their own back yards, and create gardens that reduce flood risk.





02

NOW YOU'RE TALKING
BY TREVOR COX
OUT NOW (£20, THE
BODLEY HEAD)



HAVE A NATTER

Acoustic engineer TREVOR COX (pictured below) makes everything from concert halls to washing machines sound better, and now he's turning his attention to the mysteries of human conversation. HELEN GLENNY asks him what he's learned...

When do we start learning speech?

From about the third trimester of pregnancy a baby can start hearing the vague sounds of a mother's voice, and when a baby is born it recognises that voice in preference to any others. It doesn't recognise its father's, because it hasn't had that same intimate connection.

How does the voice change over a lifetime?

There is a big change at puberty – that's when we get our adult voice. It's most obvious with boys, but female voices drop too. But what's remarkable about the voice is that it doesn't really deteriorate with age until you're very old; I'm in my 50s and I'm covered in wrinkles and my body is gradually falling apart, but my voice isn't that different from when I was 20.

You say we make assumptions about people based on their voices...

Yes, and one that I'm fascinated by is the gay male voice. We have this situation where people assume that gay males automatically talk at a higher pitch, but if you compare straight and gay men, and do measurements, there's no difference. During my childhood, the only gay males I knew of were camp characters like Larry Grayson. We didn't have gay male role models who spoke as everyone else did, so I expect that stereotype might wane over time – hopefully it does, because it's incorrect.

Speech isn't purely the domain of humans any more. Google's voice

assistant can book appointments over the phone, and it sounds real. How?

Those voices are already pretty good, but Google added the 'uh-huhs' and 'mmms' that we use when we're thinking, which makes it sound more natural. Another clever thing is that they did it down a phone line, so if there's any roboticism, the listener will assume it's a mobile phone issue.



As well as talking, robots are singing now too, right?

The best example is Hatsune Miku who does Japanese pop. People turn up to Hatsune's concerts and listen to her sing, even though she's just a synthesiser and light projections. There's a robotic aesthetic in Japanese pop, so you'd struggle to pick that her voice is synthesised. There's a lot about the voice of a singer-songwriter like Adele that we just can't do with synthesis yet.

What about robot actors?

I went and saw a robot perform 'Alas, poor Yorick!' [a speech from *Hamlet*] recently. It was funny, because the speech is all about mortality, something a robot doesn't suffer from – I guess until a software update means it doesn't work any more.

FIND OUT MORE

Listen to our interview with Trevor Cox on the Science Focus podcast. Visit sciencefocus.com/sciencefocuspodcast

AUTHOR'S BOOKSHELF

Five books that inspired Trevor Cox while writing *Now You're Talking*



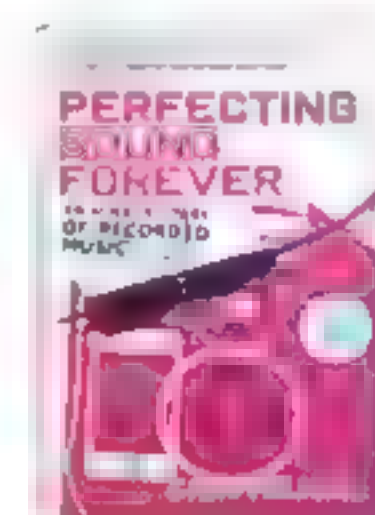
THIS IS YOUR BRAIN ON MUSIC: UNDERSTANDING A HUMAN OBSESSION
BY DANIEL LEVITIN
(£7.99, DUTTON PENGUIN)

My favourite book that explores the neuroscience of music.



MUSICOPHILIA: TALES OF MUSIC AND THE BRAIN
BY OLIVER SACKS
(£8.99, KNOPE)

Case studies of people struggling with neurological conditions reveal how the brain works.



PERFECTING SOUND FOREVER: AN AURAL HISTORY OF RECORDED MUSIC
BY GREG MILNER
(£9.99, GRANTA BOOKS)

Reading Greg's account of early sound recording inspired me to research how the voice is changed by technology.



SWEARING IS GOOD FOR YOU: THE AMAZING SCIENCE OF BAD LANGUAGE
BY EMMA BYRNE
(£12.99, PROFILE BOOKS)

For all connoisseurs of potty-mouthed speaking.



THE EVOLUTION OF LANGUAGE
BY W. TECUMSECH FITCH
(£40.99, CAMBRIDGE UNIVERSITY PRESS)

A comprehensive account of language evolution, including drawing on Fitch's fascinating research.



VISIT LONDON FOR A SUMMER OF SCIENCE

From international challenges to interactive experiments, these events will add some fascinating new science to sunny days spent in the city.

1 **FUTUREFEST** TOBACCO DOCK, LONDON 6-7 JULY 2018

If you're wondering where technology's taking us, FutureFest will give you answers. With a fascinating combination of politics, philosophy and science, you'll hear talks from health campaigners, start-up CEOs, and artists. We're looking forward to gaining a new appreciation of how futurists are solving the biggest challenges of our time, like food insecurity, income inequality and the dwindling job market.

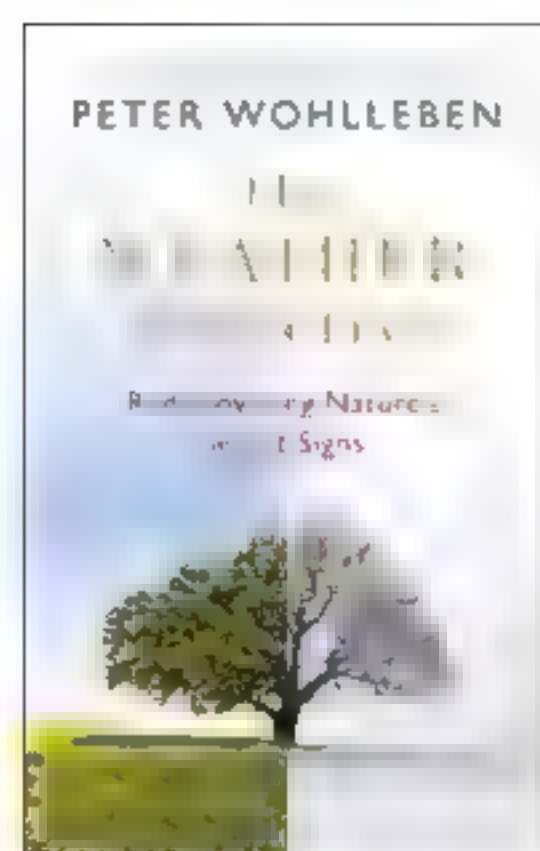
2 **TEDX CLAPHAM** THE CLAPHAM GRAND, LONDON 17 JUNE 2018

Clapham's gearing up for its biggest TED event so far, with thought-provoking talks from experts in all areas. We're eager to hear how Richard Ballard is managing to grow greens in disused WWII air raid shelters 30 metres under the streets of London, and we can't wait for evolutionary anthropologist Anna Machin's talk – she's exploring the neuroscience of relationships, be that lover, friend or family member.

3 **ROYAL SOCIETY SUMMER SCIENCE EXHIBITION** THE ROYAL SOCIETY, LONDON 2-8 JULY 2018

Get yourself along to one of the year's most hands-on science events, covering everything from malaria vaccines to space exploration. You can control a robotic arm with the electricity of your own muscles, learn why some people are genetically vulnerable to psychopathy, and do a life drawing of a naked mole rat.





04

**THE WEATHER DETECTIVE:
REDISCOVERING NATURE'S
SECRET SIGNS**
BY PETER WOHLLEBEN
OUT NOW (£12.99, RIDER)

PREDICT THE WEATHER

Delete your weather app – the best forecasters are birds, plants and animals. Ecology expert PETER WOHLLEBEN offers five ways that nature can help you predict the weather

Red sky at night, shepherd's delight

Evening sun setting with a warm, rosy glow is taken as a sign of sunshine the following morning. Sunbeams stream in from the clear skies in the west and light up the clouds drifting off to the east. In Europe, the weather usually comes from the west, so a cloudless western horizon means clear skies for the following few hours.

Red sky in the morning, shepherd's warning

This is usually right, if the weather is coming from the west. If there are red skies in the morning, then it means the Sun rising in the east is illuminating clouds gathering in the west. Every rule has its exception, of course. If the wind blows not from the west, but from the south or the east, red skies at sunset or sunrise bear no prophetic significance.

Dew and hoarfrost

Fog occurs when water vapour can no longer disperse into the air because the air is already saturated. Cold air can't hold much water, unlike warm air which can hold a lot. This is why foggy weather is particularly common in the colder half of the year.

If the temperature drops sharply at night, the air can no longer hold the water and 'sweats' it out. Small droplets accumulate on the ground as dew or, if the air temperature falls below freezing, as hoarfrost. Such a sharp drop in temperature is caused by relatively dry air, with little excess water to form



clouds, so when you see this phenomenon, you can generally bet that the weather that day will be fine.

Open daisies

If rain is on the way, daisy petals close up to avoid letting a single drop in, and some even droop downwards. When the weather is fine, however, they remain open. This entire response mechanism only functions during the day, because daisies close up shop in the evenings, like many other flowers.

This opening and shutting mechanism is due to a difference in growth between the upper and lower surfaces of a petal. The upper surface grows faster at higher temperatures than the lower surface, so the flower opens up. Dark rain clouds cause low temperatures, encouraging the underside to grow faster, and making the petals close up. This process also explains why they close at night, when it's cooler.

Swarming thunderflies

The minuscule thunderfly (also known as a thrip, thunderbug or storm fly) is just one or two millimetres in length. For creatures of this size, air has the same resistance as water does for us humans, giving them a certain buoyancy; their motion is more like swimming through the air. They love hot, sticky weather with good air movement – on a warm breeze, they can travel from plant to plant much more efficiently. It is precisely these conditions (sultry air and rising winds) that emerge

when a storm is brewing, so that's when you'll see the air swarm with these tiny pests.

05 GO MAD ON DINOSAURS

Twenty-five years ago we sat down, popcorn in hand, to watch *Jurassic Park* for the first time (and now we feel old). Celebrate this month by doing all things dinosaur...

1. WATCH THE MOVIE

At *Jurassic Park In Concert* you'll see the film on the big screen, accompanied by the Czech National Symphony Orchestra playing the movie's iconic score. It's touring around the country from September to December, playing at 14 different venues.

VARIOUS UK LOCATIONS

7 SEPTEMBER – 5 DECEMBER

2. VISIT JURASSIC WORLD

Take a trip to Paris to stare down a *Velociraptor* and take on a *T. rex* at *Jurassic World: The Exhibition*. Created in collaboration with palaeontologist Jack Horner, you can learn all about the real world science behind these prehistoric creatures.

LA CITÉ DU CINÉMA, PARIS
UNTIL 2 SEPTEMBER

3. HUNT FOR FOSSILS

The UK Association of Fossil Hunters runs events every few weeks for budding palaeontologists. Enthusiasts of any age or experience level are welcome, and it's a great way to learn how to collect fossils responsibly from sites all over the UK.

VARIOUS UK LOCATIONS

APPROX 20 EVENTS PER YEAR

4. TRAVEL BACK IN TIME

Board the time machine at *Dinosaurs In The Wild* in Greenwich and emerge in the Cretaceous Period. You'll tour a scientific research station, see *Alamosaurus* and *Triceratops* roaming the plains, and even witness an autopsy on a giant dinosaur.

WEST PARKSIDE, GREENWICH
PENINSULA, LONDON
UNTIL 31 JULY

5. READ THE STORY OF THE DINOSAURS

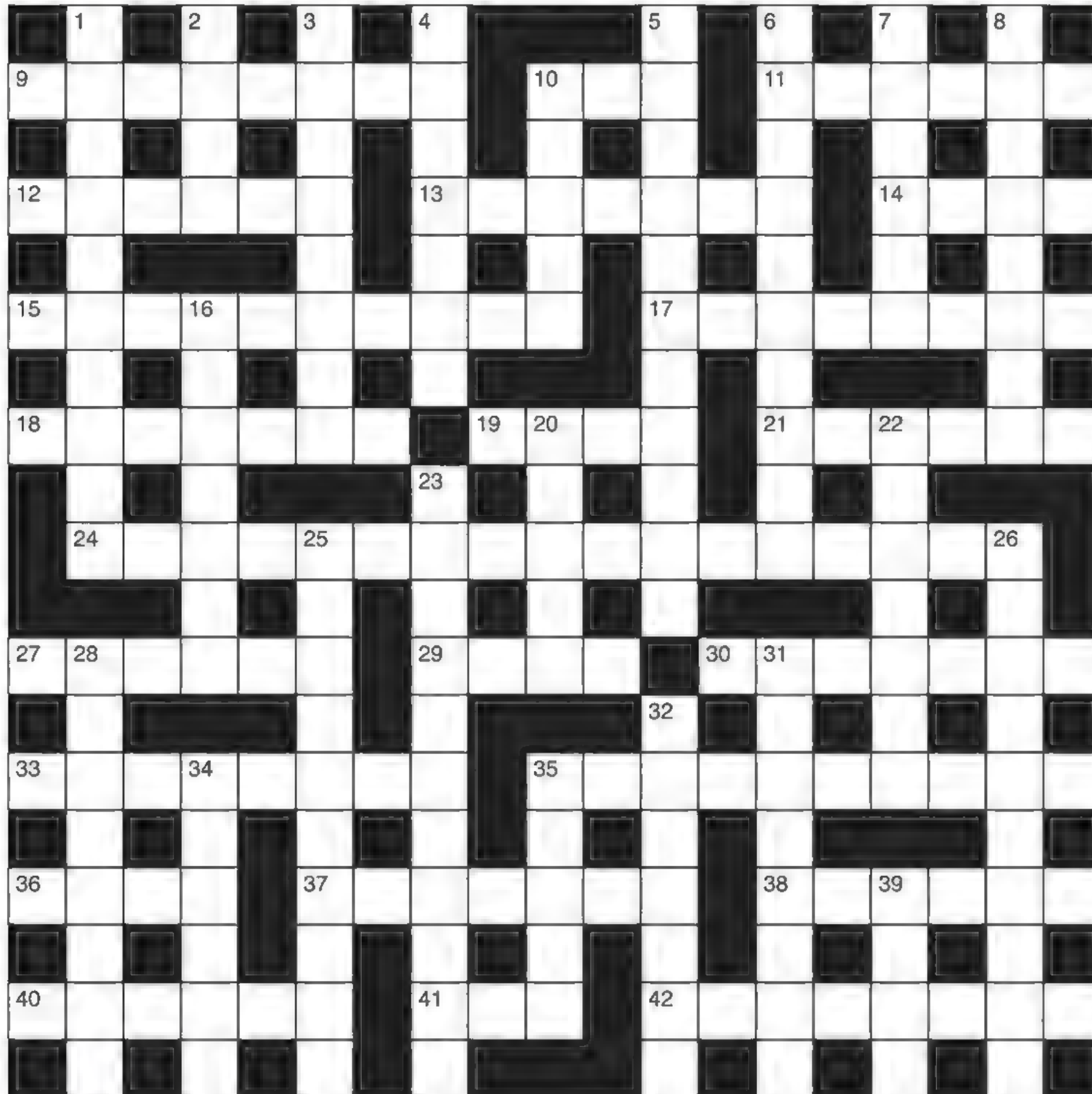
The dinosaur empire lasted for 150 million years, and thanks to modern science, we're now piecing together their story. Palaeontologist Stephen Brusatte claims there's a lot we can learn from these mighty creatures, and it's all in his new book.

THE RISE AND FALL
OF THE DINOSAURS
OUT NOW (£20, MACMILLAN)



BBC FOCUS CROSSWORD

GIVE YOUR BRAIN A WORKOUT



DOWN

- 1 Brief order gets drinks supplier some broadband (5,5)
- 2 Note about success (4)
- 3 Bankers worked out answer – it's about Lincoln (8)
- 4 Physic treated catholic prophet (7)
- 5 Eatery with a rubbish dishwasher? (6,5)
- 6 A, for example, family gathering (5,5)
- 7 Sign of slovenliness shows Shakespearean spirit (6)
- 8 Jack, say, to confront eccentric (4,4)
- 10 Youngster initially belittling terrible rain (5)
- 16 Online message about one old variable subject (7)
- 20 Dirt not starting on the German – a bit of a cow (5)
- 22 Important lies about getting a book (7)
- 23 Metalworker has a couple of drinks (11)
- 25 Clairvoyant gets gullible person some material (10)
- 26 River tours generate replicating infection (10)
- 28 Sane to share with a student (8)
- 31 Poetic muse to name Galilean moon to get exercise (8)
- 32 Work so carelessly to get amount to marsupial (7)
- 34 Obsessive collector plays game with Greek character (6)
- 35 Dexterous with large earthenware (5)
- 39 Artist pursues silver to former capital (4)

ACROSS

- 9 Heard **soprano's** notes on the ocean (4,4)
- 10 Bit of gold found in pub (3)
- 11 Laugh at idiot returning sponge (6)
- 12 Box on right shows sign of damage (6)
- 13 City that was elegant in the past (7)
- 14 Navy bird (4)
- 15 Firing company doctor gets you and me into trouble (10)
- 17 Hindu spirituals tolerate animated character (4,4)
- 18 Seat of an empire (7)
- 19 Collision shows sign of expectancy (4)
- 21 Able to play, but is done incorrectly (6)
- 24 Angry exchange, finding clip more about me (9,8)
- 27 Large design has unknown diamond pattern (6)
- 29 Noble exclamation (4)
- 30 Emphasises different way to speak (7)
- 33 A moister form of spray (8)
- 35 Expanding, taking record for shaving (10)
- 36 Medal for a percussionist? (4)
- 37 Arch construction given the French regnal name (7)
- 38 Character showing inclination (6)
- 40 Detest having left one form of salt (6)
- 41 Middle of spell needs foot of newt (3)
- 42 Higher-level reduction came as a blow (8)

ANSWERS

For the answers, visit bit.ly/BBCFocusCW
Please be aware the website address is case-sensitive.



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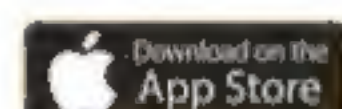
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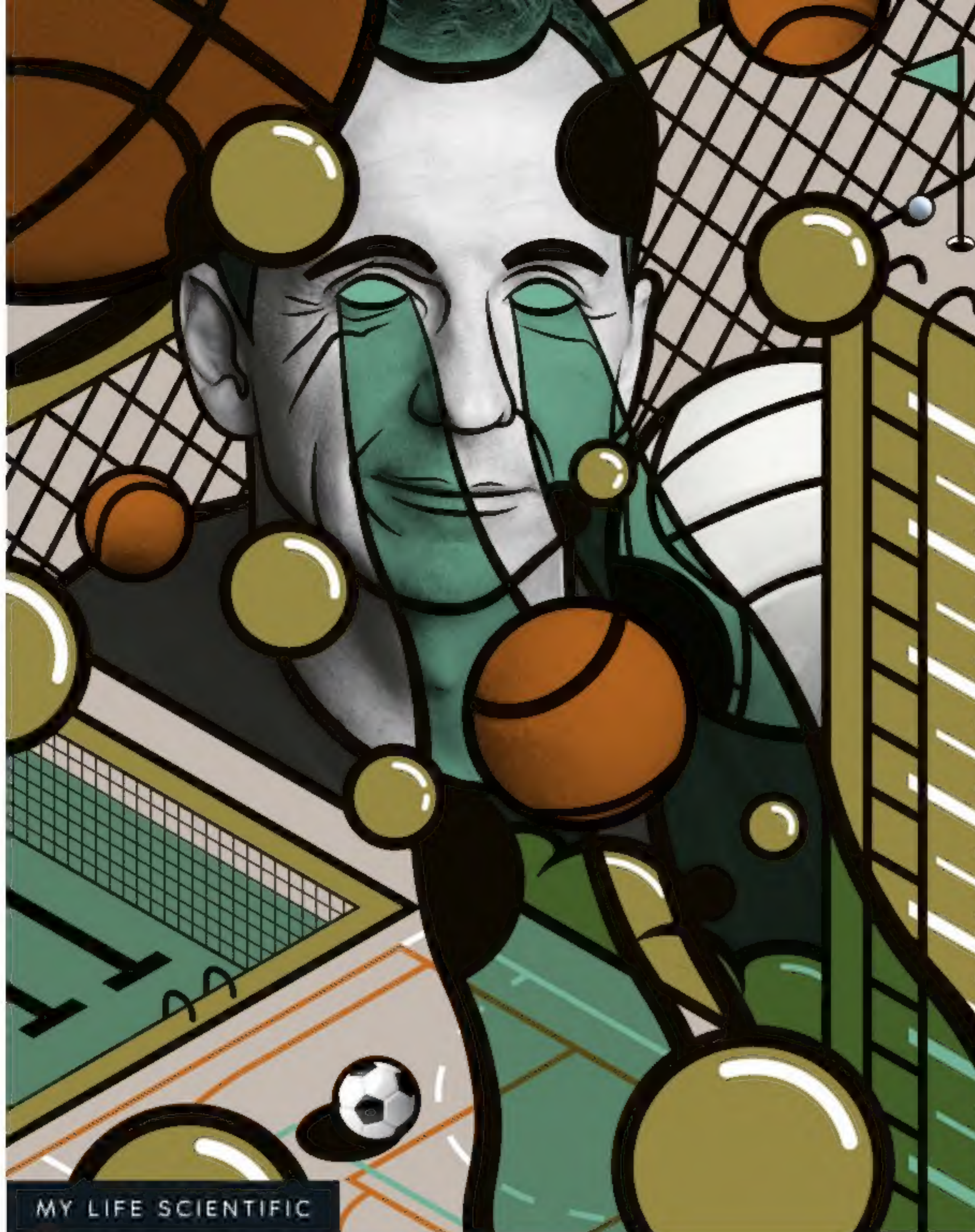
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Greg Whyte

This month, sports scientist and former Olympian **Greg Whyte** talks to **Helen Pilcher** about fencing skulduggery, Comic Relief and why doughnuts are no bad thing...

Greg Whyte comes from a family of athletes. His dad was a former amateur boxer and his uncle was a footballer.

Have you always loved sport?

It's been a lifelong obsession. My passion at school was swimming, then when I was 14 there was a scandal that transformed my life. It was 1976, the height of the Cold War. The British pentathlon team was fencing the Russians in the Montreal Olympics. The British captain got hit by a Russian fencer, but he complained. They checked the Russian's sword and found it had a secret button. The Russians were thrown out for cheating and Britain went on to win. It raised the profile of British modern pentathlon.

So you took up pentathlon?

It became the next 15 years of my life. It took me to the Olympics, and European and World Championships. I had an incredible career. You learn to cope with failure and with success.

How did you move into sport science?

When I was competing, there was no money, so you either worked or studied. I did one of the first degrees in sport science, then became involved in research. I'm running a study for patients with oesophageal cancer. Surgery is a physiological insult, so exercise can help prepare the body. It's fantastic work.

"MOVE MORE.
IT'S THAT SIMPLE"

You are known for your work with Comic Relief. How did that come about?

I remember it vividly. It was a drizzly day when I got a phone call from the CEO of Comic Relief. He'd just returned from Ethiopia with David Walliams, and they wanted to set up a big challenge. David said he would swim the English Channel. Two days later he was in my lab being tested.

Did you swim the Channel with him?

I trained him every stroke of the way, and on the day I was in the water pacing him. We had a good time, but it was tough. This was real TV, not reality TV – there's a huge difference. Since, I've worked on 30 challenges for Sport and Comic Relief.

What was the toughest challenge?

David swimming the Channel was remarkable, but Jo Brand walking 20 miles a day for 7 days was an incredible achievement for where she had come from, which was virtually inactive. It's not about the size of the challenge. Her journey to that point was truly amazing.

Of what are you most proud?

I've helped raise over £40m for Comic Relief, received an OBE for services to sport science and got to meet the Queen, but my proudest moments are the ones that are unseen. I'm really proud of the work I do with cancer patients because it makes such a big difference to their lives.

Do you have any vices?

I enjoy a glass of wine, a strawberry sugared doughnut and a bag of chips. Balance is important. I don't want to be a health zealot, because it's not the way people live their lives.

One message for our readers?

Move more. It's that simple. 🏃

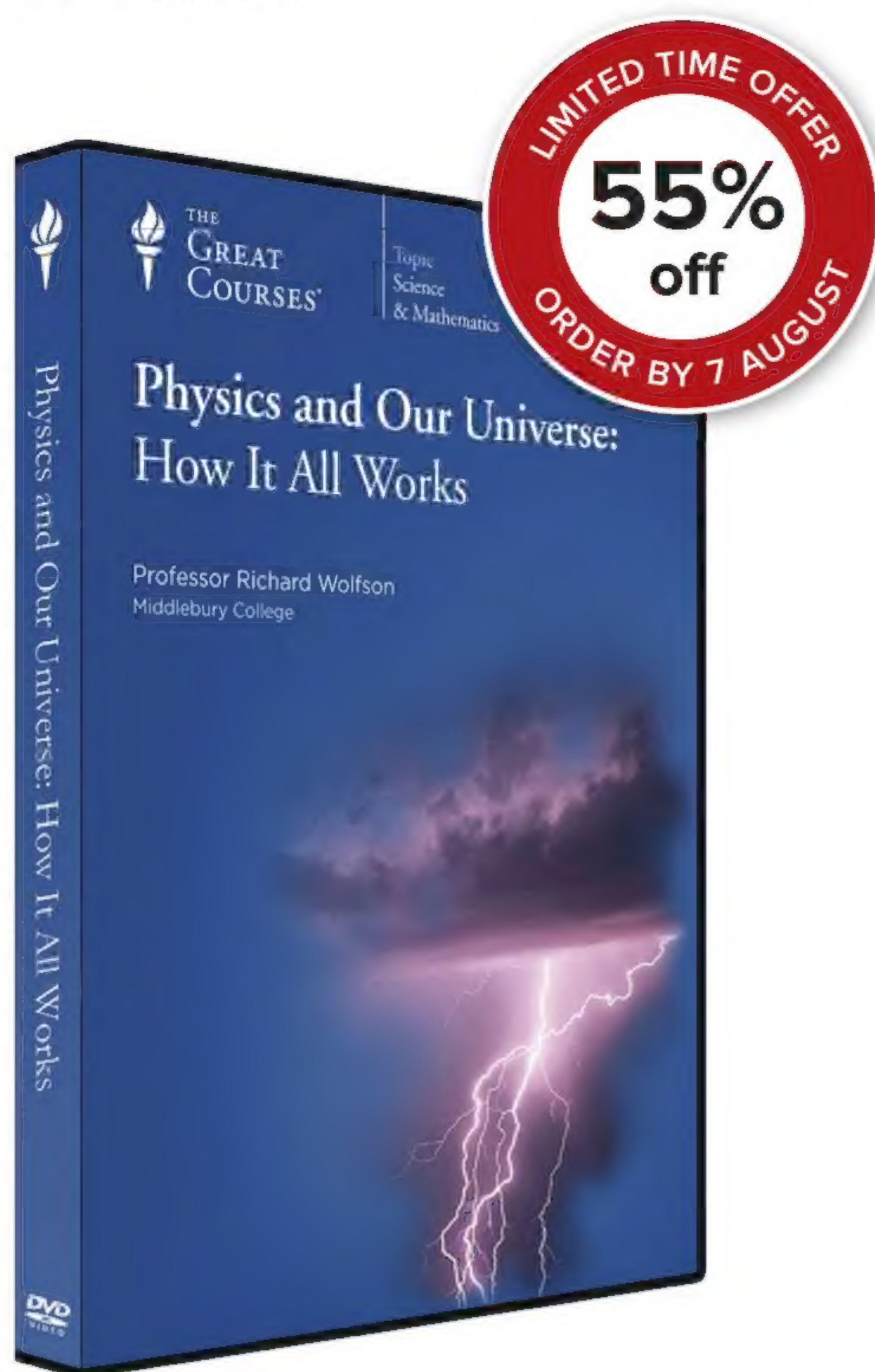
Greg Whyte is a professor of applied sport and exercise science at Liverpool John Moores University, and director of performance at London's Centre for Health and Human Performance.

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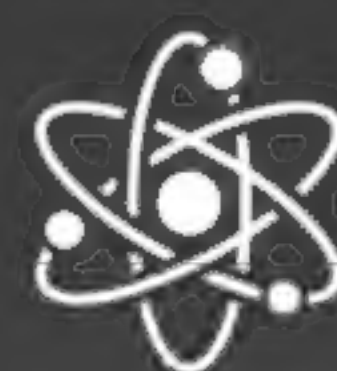
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